PB 210 640

VEHICLE OPERATIONS SURVEY

VOLUME I

PREPARED FOR

COORDINATING RESEARCH COUNCIL, INC.
30 Rockefeller Plaza
New York, New York 10020

AND

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS

MOBILE SOURCE POLLUTION CONTROL PROGRAMS
2565 Plymouth Road
Ann Arbor, Michigan 48105

SCOTT RESEARCH LABORATORIES, INC.
P. O. BOX 2416
SAN BERNARDINO, CALIFORNIA 92406

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

BIBLIOGRAPHIC DATA SHEET

1. Report No. CRC-APRAC-CAPE-10-68-9

2.

3. Recipient's Accession No. PB 210 640

4. Title and Subtitle

Vehicle Operations Survey -- Volume I

5. Report Date December 17, 1971

6.

7. Author(s)

8. Performing Organization Rept. No. SRL 2922-13-1271

9. Performing Organization Name and Address

Scott Research Laboratories, Inc.
2600 Cajon Boulevard, P.O. Box 2416
San Bernardino, California 92406

10. Project/Task/Work Unit No. CAPE-10-68

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

Coordinating Research Council, Inc., 30 Rockefeller Plaza, New York, New York 10020 and Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, Michigan 48105

13. Type of Report & Period Covered

Final

14.

15. Supplementary Notes

Releasable to the public in July 1972

16. Abstracts

The purpose of the program was to define, determine, and typify automobile driving patterns in terms of operating modes. Data were collected in five major metropolitan areas and subsequently combined to form an overall composite of urban driving patterns. Three surveyor vehicles were instrumented with digital data acquisition systems for use in the field. The "chase-car" concept was utilized, whereby the instrumented vehicles were operated to emulate the driving patterns of various cars representing the traffic population. Operating parameters of vehicle speed, time, and manifold vacuum, together with various route descriptors, were obtained from the chase vehicle and recorded on magnetic tape for computer batch processing. The data were processed to identify and summarize the basic vehicle operating modes: acceleration, deceleration, cruise, and idle. Mode characteristics such as frequency of occurence, total duration, average duration, and transition probability were defined in matrix form.

17. Key Words and Document Analysis. 17a. Descriptors

Idle Time
Automobile
Manifold Vacuum
Acceleration
Deceleration

Details of illustrations in
this document may be better
studied on microfiche

17b. Identifiers/Open-Ended Terms

Los Angeles, California
Houston, Texas
Cincinnati, Ohio
Chicago, Illinois
New York City, New York
Detroit, Michigan

17c. COSATI Field/Group 21B; 13F

I

18. Availability Statement

Releasable to the public

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 154

22. Price 3.00 - 0.95

FORM NTIS-35 (10-70)

USCOMM-DC 40329-P71

Final Report

Vehicle Operations Survey

CRC APRAC Project No. CAPE-10-68 (1-70)

Volume I

Prepared for

Coordinating Research Council, Inc.
30 Rockefeller Plaza
New York, New York 10020

and

Environmental Protection Agency
Office of Air Programs
Mobile Source Pollution Control Program
2565 Plymouth Road
Ann Arbor, Michigan 48105

December 17, 1971

by

SCOTT RESEARCH LABORATORIES, INC.
2600 Cajon Boulevard, P.O. Box 2416
San Bernardino, California 92406

II

TABLE OF CONTENTS

1.0 SUMMARY 1-1

2.0 INTRODUCTION 2-1

- 2.1 PROGRAM OBJECTIVES 2-1
- 2.2 BACKGROUND INFORMATION 2-1
- 2.3 SCOPE OF OPERATIONS 2-2

3.0 PROGRAM DESCRIPTION 3-1

- 3.1 GENERAL APPROACH 3-1
  - 3.1.1 PREPARATORY EFFORTS 3-1
  - 3.1.2 DATA COLLECTION OPERATIONS 3-2
  - 3.1.3 DATA HANDLING 3-3
- 3.2 INSTRUMENTATION SYSTEMS 3-3
  - 3.2.1 VEHICLES USED FOR COLLECTING DATA 3-4
  - 3.2.2 TRANSDUCERS 3-5
  - 3.2.3 DIGITAL DATA ACQUISITION SYSTEM 3-8
  - 3.2.4 INSTRUMENT POWER SUBSYSTEM 3-12
- 3.3 SURVEY ROUTE DESIGN 3-19
  - 3.3.1 ROUTE DESIGN OBJECTIVES 3-19
  - 3.3.2 ROUTE DESIGN FACTORS 3-20
  - 3.3.3 ROUTE-MODEL STRUCTURE 3-20
  - 3.3.4 SURVEY ROUTE DESIGN 3-25
- 3.4 DATA COLLECTION OPERATIONS 3-33
  - 3.4.1 TRAINING OF PERSONNEL 3-33
  - 3.4.2 DATA COLLECTION SCHEDULE 3-38
  - 3.4.3 OPERATING TECHNIQUE 3-38

III

TABLE OF CONTENTS (CONT.)

3.4.4 VEHICLE OPERATIONS SURVEY ON THE LA-4 ROUTE 3-43

3.5 DATA PROCESSING AND ANALYSIS TECHNIQUES 3-46

3.5.1 DATA PROCESSING TECHNIQUES 3-46

3.5.2 DATA ANALYSIS PROCEDURES 3-84

4.0 RESULTS 4-1

4.1 DATA COMPARISONS 4-1

4.1.1 COMPARISON OF BASIC DESCRIPTORS 4-2

4.1.2 MODE COMPOSITION 4-4

4.1.3 CORRELATION OF MATRIX INFORMATION 4-9

4.1.4 DELTA-SQUARE EVALUATION 4-14

4.1.5 SUPPLEMENTAL INFORMATION 4-14

4.2 LOS ANGELES ROUTE REPLICATE EVALUATION 4-25

4.2.1 NORMALIZED TIME IN MODE VARIABILITY 4-25

4.2.2 NORMALIZED MODE FREQUENCY VARIABILITY 4-27

4.2.3 DELTA-SQUARE COMPARISON OF ROUTE REPLICATES 4-27

4.2.4 AVERAGE SPEED VARIABILITY 4-27

4.2.5 CORRELATION BETWEEN ROUTE REPLICATE MATRICES AND THE LOS ANGELES COMPOSITE FOR NORMALIZED TIME IN MODE DATA 4-27

4.2.6 CORRELATION BETWEEN ROUTE REPLICATE MATRICES AND THE LOS ANGELES COMPOSITE MATRIX FOR NORMALIZED MODE FREQUENCY 4-27

4.2.7 SUMMARY OF ROUTE REPLICATE EVALUATION 4-32

4.3 DETROIT ROAD ROUTE 4-32

4.3.1 DESIGN OF THE ROUTE METROPOLITAN ROAD ROUTE 4-32

TABLE OF CONTENTS (CONT.)

4.3.2 OPERATING PROCEDURES 4-35

4.3.3 RESULTS 4-35

4.4 SUMMARY OF RESULTS 4-42

REFERENCES R-1

LIST OF TABLES

		Page No.
Table 3-1	Typical Route Model Structure for Weekdays	3-23
Table 3-2	Correlation of Trip Length Distribution - Weekday Routes	3-26
Table 3-3	Correlation of Trip Length Distribution - Weekend Routes	3-27
Table 3-4	Survey Route Design Characteristics	3-28
Table 3-5	Data Collection Schedule - Vehicle Operations Survey	3-39
Table 3-6	Differences Between LA Composite and LA-4 Survey Parameters	3-45
Table 4-1	Comparison of Basic Descriptors of Vehicle Operation	4-3
Table 4-2	Distribution of Total Time in Mode Categories	4-6
Table 4-3	Distribution of Mode Frequency in Mode Categories	4-8
Table 4-4	Correlation Coefficients Normalized Time in Mode Comparison	4-10
Table 4-5	Correlation Coefficients Normalized Frequency of Occurrence Comparison	4-12
Table 4-6	Delta-Square Values for Each City Versus the 5-City Composite	4-15
Table 4-7	Overall Matrix Similarity Δ-Square Values	4-16
Table 4-8	Mode Composition for Route Replicates in Los Angeles - Percent of Time in Mode	4-26
Table 4-9	Mode Composition for Route Replicates in Los Angeles-Percent of Mode Frequency	4-28
Table 4-10	Delta-Square Values and Average Speeds for Route Replicates in Los Angeles	4-29
Table 4-11	Correlation of Route Replicates with LA Composite Matrix: Normalized Time-in-Mode	4-30
Table 4-12	Correlation of Route Replicates with LA Composite: Normalized Mode Frequency	4-31

LIST OF TABLES (CONT.)

		Page No.
Table 4-13	Summary of Route Replicate Evaluation	4-33
Table 4-14	Construction Characteristics of Detroit (Ann Arbor) Road Routes	4-36
Table 4-15	Comparison of Vehicle Operating Patterns on Detroit Road Routes with the Five-City Composite Results	4-39
Table 4-16	Improvement of Detroit Road Route Characteristics by Adding Idle Time	4-41

LIST OF FIGURES

		Page No.
Figure 3-1	Functional Block Diagrams, VOS Mobile Instrument System	3-6
Figure 3-2	Instrumentation Component Locations, VOS Vehicle	3-9
Figure 3-3	VOS Control Display Panel	3-11
Figure 3-4	Control/Display Panel and Power Control Unit Installed on the VOS Vehicle Dash	3-13
Figure 3-5	Data Acquisition Unit, Magnetic Tape Recorders, and 115 VAC Inverter Mounted in VOS Vehicle Rear Deck (a) Accessibility of Electronic Circuit Cords (b) Ready for Survey Operations	3-14
Figure 3-6	Rear of Instrument Racks Containing the Data Acquisition Unit, Magnetic Tape Recorder, and Inverter (a) Ready for Survey Operations (b) Access to System Cables and Batteries	3-15
Figure 3-7	VOS Power Control/Monitor Unit	3-17
Figure 3-8	Instrument System Alternator and Regulator Installation in a VOS Vehicle	3-18
Figure 3-9	Relationships Between Factors Affecting Route Design	3-21
Figure 3-10	General Form of Trip Descriptor Functional Relationships	3-22
Figure 3-11	Distribution of Trips by Time of Day and Purpose of Trip (Weekdays)	3-29
Figure 3-12	Route Directory Sample Page	3-31
Figure 3-13	Speed-Time Traces From Lead Car and Chase Car	3-35
Figure 3-14	Vehicle Make Code	3-36
Figure 3-15	Weather Codes	3-37
Figure 3-16	LA-4 Road Route Description	3-44
Figure 3-17	Mode-Selection Logic	3-50
Figure 3-18	Segmentation of Speed/Time Data Into Modes Using Preliminary Mode Logic	3-52
Figure 3-19	Matrix Representation of Vehicle Operation	3-54

LIST OF FIGURES (CONT.)

Page No.

Figure 3-20 Master Mode Matrix 3-55

Figure 3-21 Vehicle Operation Mode Matrices 3-57

Figure 3-22 Transition Probability Matrix 3-58

Figure 3-23 Matrix of Average Speed Versus Trip Length and Time of Day 3-60

Figure 3-24 Acceleration-Rate-Versus-Instantaneous-Speed Matrix 3-62

Figure 3-25 Manifold Vacuum Versus Cruise Speed 3-64

Figure 3-26 Compact Matrix Grid Overlaid on 70 x 70 Mode Matrix Grid Structure 3-68

Figure 3-27 Modified Logic for Segmenting Speed/Time Data Into Modes 3-71

Figure 3-28 Segmentation of Speed/Time Data Into Modes Using Modified Mode Logic 3-72

Figure 3-29 Normalized Time in Mode Matrix 3-75

Figure 3-30 Normalized Mode Frequency Matrix 3-76

Figure 3-31 Time, Distance and Average Speed Versus Time of Day and Road Type Matrices 3-78

Figure 3-32 VOS Data Conversion and Data Processing Computer Programs 3-80

Figure 3-33 VOS Auxiliary Data Processing Computer Programs 3-81

Figure 3-34 IBM Los Angeles Data Center S/370 Model 155 Computer Facilities 3-85

Figure 3-35 Mode Matrix Partitioning For Delta-Square Analysis 3-89

Figure 3-36 Matrix Mode Categories For Linear Regression Analysis 3-91

Figure 4-1 Relative Correlation of Each City versus the Composite 4-13

Figure 4-2 Acceleration Rate versus Instantaneous Speed: 5-City Composite 4-18

LIST OF FIGURES (CONT.)

Page No.

Figure 4-3 Distribution Functions of 5-City-Composite Accelerations at Various Instantaneous Speeds 4-19

Figure 4-4 Distribution Function of 5-City-Composite Decelerations at Various Instantaneous Speeds 4-20

Figure 4-5 Average 0-30 mph Acceleration Profile for Each City 4-21

Figure 4-6 Average 30-0 Deceleration Profile for Each City 4-22

Figure 4-7 Intake Manifold Vacuum Versus Cruise Speed 4-24

Figure 4-8 Data Collection Schedule for Detroit (Ann Arbor) Road Routes 4-37

Acknowledgments

Scott Research Laboratories, Inc. wish to express appreciation to the CRC-APRAC CAPE-10-68 committee members for their technical direction in the conduct of this program. Special thanks are offered to the EPA representative, Dr. Thomas Huls, and the CRC Project Manager, Alan E. Zengel, for the assistance offered during the various phases of the effort.

The Vehicle Operation Survey was performed under the guidance of John Harkins, Laboratory Director. Malcolm Smith acted as Program Manager and Michael J. Manos functioned as Project Engineer. Other Scott personnel contributing materially to the successful completion of this project were: J. Marrin and R. G. Kinne - instrumentation and vehicle preparation; G. Huibregtse - data processing and analysis; and S. Fischer - report preparation.

1.0 SUMMARY

This report presents the results of CRC-APRAC Project No. CAPE-10-68, entitled Vehicle Operations Survey, conducted under joint sponsorship of the Environmental Protection Agency and the Coordinating Research Council, Inc. The purpose of the program was to define, determine, and typify automobile driving patterns in terms of operating modes. Data were collected in five major metropolitan areas and subsequently combined to form an overall composite of urban driving patterns.

Data relating to basic vehicle usage patterns were obtained from a preliminary program conducted by Systems Development Corporation (SDC). Results of this initial study were utilized in the design and construction of traffic survey routes for the metropolitan areas of Los Angeles, Houston, Cincinnati, Chicago, and New York City. The SDC reports were also useful in determining the parameters of vehicle operation to be surveyed during the subject program.

Three surveyor vehicles were instrumented with digital data acquisition systems for use in the field. The "chase-car" concept was utilized, whereby the instrumented vehicles were operated to emulate the driving patterns of various cars representing the traffic population. Operating parameters of vehicle speed, time, and manifold vacuum, together with various route descriptors, were obtained from the chase vehicle and recorded on magnetic tape for computer batch processing.

The data were processed to identify and summarize the basic vehicle operating modes: acceleration, deceleration, cruise, and idle. Mode characteristics such as frequency of occurrence, total duration, average duration, and transition probability were defined in matrix form. Supplementary information was obtained on average trip speed, acceleration-deceleration profiles, and manifold vacuum rates at various cruise conditions.

Evaluation measures were defined to determine driving pattern similarities between cities and variability within a city. Merging of data from all cities yielded an overall composite of vehicle operation. A road route representing this five-city composite was constructed in the metropolitan Detroit area.

Volume I of this report discusses the program objectives, procedures, and analysis of results. Volume II is an Appendix volume which provides additional detailed information on instrumentation, survey route design, data processing, and program results.

2.0 INTRODUCTION

This section states the objectives of the Vehicle Operation Survey program, relates some of the background information pertinent to the project, and presents the basic scope of operations.

2.1 PROGRAM OBJECTIVES

The primary objective of the Vehicle Operation Survey program was to describe typical urban driving patterns. In meeting this objective, completion of the following tasks was requisite:

- Define the parameters of vehicle operation which best describe driving patterns
- Design representative urban road routes over which vehicle operating data can be collected
- Instrument vehicles for acquisition of vehicle operating data and related information
- Process the raw data to generate matrices which characterize vehicle operating modes and other descriptors of driving patterns
- Construct a composite of vehicle operating patterns based on data from all cities and design a road route in the greater Detroit area which can be said to represent the overall composite.

2.2 BACKGROUND INFORMATION

Studies were performed in 1964-1965 to establish vehicle operating patterns for the Los Angeles area*. Engine rpm and manifold vacuum data, obtained from a vehicle operating within a 6-mile radius of central Los Angeles, were used to construct a road route (LA-4) and related dynamometer cycle (XC-15), both of which typify morning rush-hour driving behavior in the downtown area.

---

* References 1 and 2.

The first part of the CAPE-10 program was conducted by the System Development Corporation. They performed surveys in the urban areas of Los Angeles, Houston, Cincinnati, Chicago, New York City, and Minneapolis-St. Paul to determine vehicle-usage patterns. Information contained in their reports* relates vehicle usage to the following trip descriptors:

- Start time
- Trip and segment distance
- Trip and segment average speed
- Number of momentary stops
- Idling time
- Road type
- Purpose of trip.

The second part of the total effort is the subject of this report. Details are contained herein, describing how the SDC information on vehicle usage was used as a tool to construct driving survey routes. The data collected on these routes became the basic input for the determination of national composite urban driving patterns.

2.3 SCOPE OF OPERATIONS

The Vehicle Operation Survey (VOS) was conducted in two phases. Phase I efforts were divided among the following tasks:

- Design, fabrication, installation, and checkout of digital data acquisition systems
- Construction of four representative driving survey routes in Los Angeles
- Training of personnel and data collection on the Los Angeles routes
- Writing of computer programs and initial processing of Los Angeles data.

---

* References 3 through 9.

Phase II activities were guided by the experience obtained during Phase I. Phase II tasks were:

- Design and construction of driving survey routes for Houston, Cincinnati, Chicago, and New York City
- Collection of data in the above four cities
- Modification of computer programs written in Phase I to optimize processing efficiency and output of useful information
- Processing of data for all five cities (including reprocessing of Los Angeles data with revised programs)
- Design, and evaluation of a road route in Ann Arbor, Michigan, which was intended to typify the five-city composite results
- Evaluation of vehicle operating patterns on the LA-4 road route for comparison with urban Los Angeles results
- Analysis of data and final report.

Throughout the duration of the data acquisition operations, two primary survey vehicles (plus one back-up vehicle) were used for collecting data in each city. The data represent a total of 22,465 miles of freeway, arterial, and capillary roads surveyed during the spring of 1971. Data collection consisted of operating (nominally) from 6:00 am to 10:00 pm for 7 consecutive days in each major urban area. Nearly 31 million pieces of information were recorded on 1/2 inch magnetic tape for subsequent computer processing.

The initial program schedule included the surveying of vehicle operating patterns in the Minneapolis-St. Paul area. This task was dropped, however, in favor of conducting an evaluation of the LA-4 road route, not originally included in the project plans.

No data collected during the course of program were considered unusable due to extreme weather effects on traffic flow. Rain was observed in all cities except Chicago; however, neither the rate nor extent of the precipitation was sufficient to create atypical driving patterns. The digital data acquisition systems performed with very few instances of malfunction. Occasional problems with electro-mechanical components were easily remedied.

The data processing programs yielded various descriptive measures of driving patterns in tabular, matrix, and graphical format. No single measure of vehicle operating patterns can be considered as adequate for representing the total pattern for a city. Therefore, a set of evaluation measures was used to analyze and compare data for each city with the other cities and with the composite.

3.0 PROGRAM DESCRIPTION

The following sections will discuss the preparations, equipment, procedures, and data processing programs used to conduct the project:

3.1 General Approach
3.2 Instrumentation Systems
3.3 Survey Route Design
3.4 Data Collection Operations
3.5 Data Processing and Analysis Techniques

3.1 GENERAL APPROACH

3.1.1 Preparatory Efforts

The groundwork was laid during the previously-conducted SDC project for the determination of the vehicle operating parameters to be considered for the VOS program. Vehicle usage trends were defined primarily in terms of a vehicle trip and descriptors of the trip. These descriptors, such as trip length, road type, purpose of trip, day of week, and time of day, were all considered in the design and construction of the driving survey routes. Traffic density effects were accounted for in a data processing routine.

Digital data acquisition systems (DDAS) were Scott designed, and fabricated under subcontract by Datum, Inc., to measure the significant parameters of vehicle operation required for describing driving patterns. Chase vehicle speed, time of day, intake manifold vacuum, and coded inputs of route descriptors were recorded on magnetic tape. Speed measurements were obtained from a rotary pulse generator, cable driven from a tee-adaptor on the transmission speedometer gear. A potentiometric gage pressure transducer and signal conditioner monitored intake manifold vacuum data. Additional coded inputs denoting day of year, make of vehicle being followed, route number, trip number, segment number, and road type were accomplished with thumbwheel selector switches. These data were recorded at a rate of one sample per second on 1/2-inch magnetic tape.

The electronic systems and digital tape recorder were cabinet-mounted behind the rear seats of the station wagons used as chase vehicles. Power for operation was supplied by two 12-volt truck batteries, maintained by an auxiliary alternator belt-driven off the engine.

3.1.2 Data Collection Operations

Vehicle operating data were collected initially in the urban Los Angeles area using the chase car concept. With this method the chase-car driver emulated the driving habits of a large sample of the vehicle population operating on representative portions of freeways, major arteries, and capillary roads.

Shortly thereafter, a similar evaluation of driving patterns was conducted on the LA-4 road route located in central Los Angeles. The processed data, describing mode operating patterns for the two surveys, were compared to determine similarities (or differences) in vehicle operation over these two routes.

Houston, Cincinnati, Chicago, and New York City urban areas were subsequently surveyed to determine driving habits in those metropolitan areas. During the course of operations, the survey vehicles operated from 6:00 a.m. to 10:00 p.m. each day over a minimum of seven consecutive days in each city.

3.1.3 Data Handling

Initial data processing requirements, including the writing and debugging of programs and the processing of Phase I (Los Angeles) data, were subcontracted to TRW Systems Group. The computer programs accomplished the following tasks:

- Convert 7-track low-density data tapes to 9-track, 800-BPI intermediate data tapes
- Edit parity errors and illegal characters
- Establish operating modes and collect acceleration/deceleration profile data on punch cards
- Generate three-dimensional speed-mode and supplementary matrices
- Merge and compact matrices; i.e., combine route replicates and rescale matrix dimensions
- Print out results and perform matrix comparison evaluations.

Prior to Phase II data processing, the computer program logic was evaluated and, under a subcontract to IBM, minor modifications were incorporated to optimize processing efficiency and obtain additional information. All of the data collected during the course of the project were processed using the revised computer programs, including the reprocessing of the Phase I LA data. Scott personnel utilized the facilities of the Los Angeles IBM service center for this task, operating on the system 370/155 computer.

3.2 INSTRUMENTATION SYSTEMS

The VOS program required the use of three instrumented vehicles for acquisition of vehicle operating data in the field. The vehicles were driven as chase cars, emulating the operating patterns of other cars.

Data on vehicle speed, intake manifold vacuum, time-of-day, and several manually-coded inputs were thus obtained from the instrumented vehicle and established as representative of the vehicles being followed.

During operation of the instrumented vehicles, data were recorded at one-second intervals on IBM-compatible digital magnetic tape and simultaneously read back and displayed for real-time verification by the instrument system operator. All data tapes were subsequently processed directly by digital computer.

Details describing the selection of chase-car vehicles, the digital data acquisition systems (DDAS), and related operating systems are presented in the following sections.

3.2.1 Vehicles Used for Collecting Data

The vehicles selected to transport the DDAS and related operating systems and to function as the chase car were 1971 Ford Ranch Wagons. Factors affecting the selection were:

- Available space in the engine compartment for mounting the auxiliary power supply alternator for the instrument system
- A recessed dash panel on the passenger side, convenient for mounting the system control/display unit
- A station wagon body style, with increased interior space, for mounting the DDAS and for transporting replacement instrument system components and magnetic recording tape during inter-city travel
- A high-powered (360 HP) engine for carrying the added weight of the instrumentation and for adequate acceleration characteristics necessary for duplicating other vehicles' operating patterns
- Air conditioning to provide a controlled temperature environment for the instrument system.

Air-adjustable shock absorbers were installed on the rear axles of each vehicle to improve handling and ensure a level attitude under the increased loading.

3.2.2 Transducers

Speed and manifold vacuum transducers were installed in each vehicle. Figure 3-1 shows these transducers and their functional relationship to the other instrument components.

Chase-vehicle speed was measured using a rotary pulse generator coupled to the transmission speedometer output shaft through a 1:1 tee-adapter. Use of the tee-adapter also permitted simultaneous operation of the vehicle speedometer.

The generator output was a series of pulses proportional to the vehicle distance traveled (10^6 pulses per mile). These pulses were supplied to the data acquisition unit where they were accumulated during a fixed time interval. During calibration of the digital speed channel, the accumulator time interval was adjusted to provide a count equivalent to vehicle speed in miles per hour, with a full scale capability of 99.99 mph. The hundredths digit, which was not recorded, was accumulated to preclude potential problems caused by any whiplash in the speedometer drive train or by vehicle electrical noise.

Calibration of the digital speed channel was performed using a calibrated fifth wheel as the comparison standard. These calibrations were performed on each of the three program vehicles before and after the Los Angeles survey operation, and after the 5-cities survey operation. Results of these calibrations, showing the deviations of the digital speed

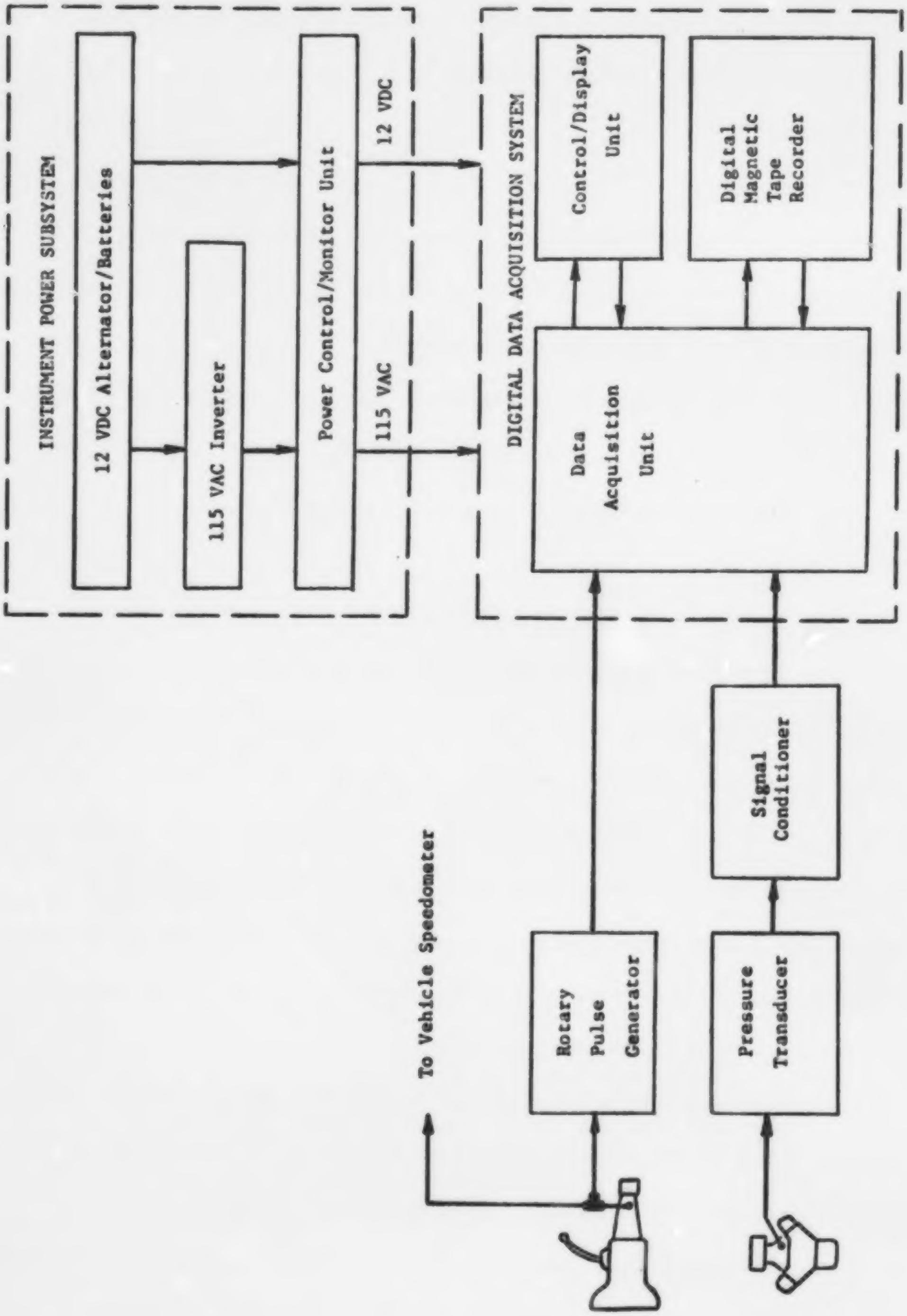

INSTRUMENT POWER SUBSYSTEM
12 VDC Alternator/Batteries
115 VAC Inverter
Power Control/Monitor Unit
12 VDC
115 VAC
DIGITAL DATA ACQUISITION SYSTEM
Control/Display Unit
Digital Magnetic Tape Recorder
Data Acquisition Unit
To Vehicle Speedometer
Rotary Pulse Generator
Pressure Transducer
Signal Conditioner

Figure 3-1. Functional Block Diagrams, VOS Mobile Instrumentation System

indications from the fifth-wheel speed indications, are presented in Appendix A-1.

Engine manifold vacuum was measured using a potentiometric pressure transducer with a pressure range of -15/0/+5 PSIG. Pressure input to the transducer was supplied from the chase-vehicle intake manifold through a snubber valve. This valve was necessary to reduce the high-frequency content of the manifold-vacuum pressure signal caused by the opening of each individual intake valve. These high-frequency pressure signals were found to be damaging to the pressure transducer.

The pressure transducer electrical signal was processed by a signal conditioner which supplied power and bridge-completion circuitry for scaling the transducer output to a -300/0/+100 millivolt signal. The -300/0/+100 scaling was adjusted during calibration of the pressure transducer to give direct readings in inches of Hg with a resolution of 0.1 in. Hg. This signal was then supplied to the data acquisition unit for analog-to-digital conversion.

Calibration of the manifold vacuum channel was performed by supplying an external vacuum source to the transducer and using a mercury manometer as a comparison standard. Calibrations were performed before and after the survey operations on each pressure transducer as installed in its companion vehicle. Results of these calibrations, showing the deviations of the pressure channel indications from the mercury manometer measurements, are presented in Appendix A-2.

The locations of the speed transducer, tee-adapter, and manifold vacuum transducer, as installed in the chase vehicles, are shown pictorially in Figure 3-2.

3.2.3 Digital Data Acquisition System

The DDAS, shown functionally in Figure 3-1, consisted of three main units: the data acquisition units, the remote control/display unit, and the digital magnetic tape recorder.

The data acquisition unit, containing all integrated circuit electronics, performed the following functions:

a. Accumulated the speed pulse data over a precisely-adjusted time interval to provide a digital count equivalent to the vehicle speed in MPH, resolved to 0.01 mph

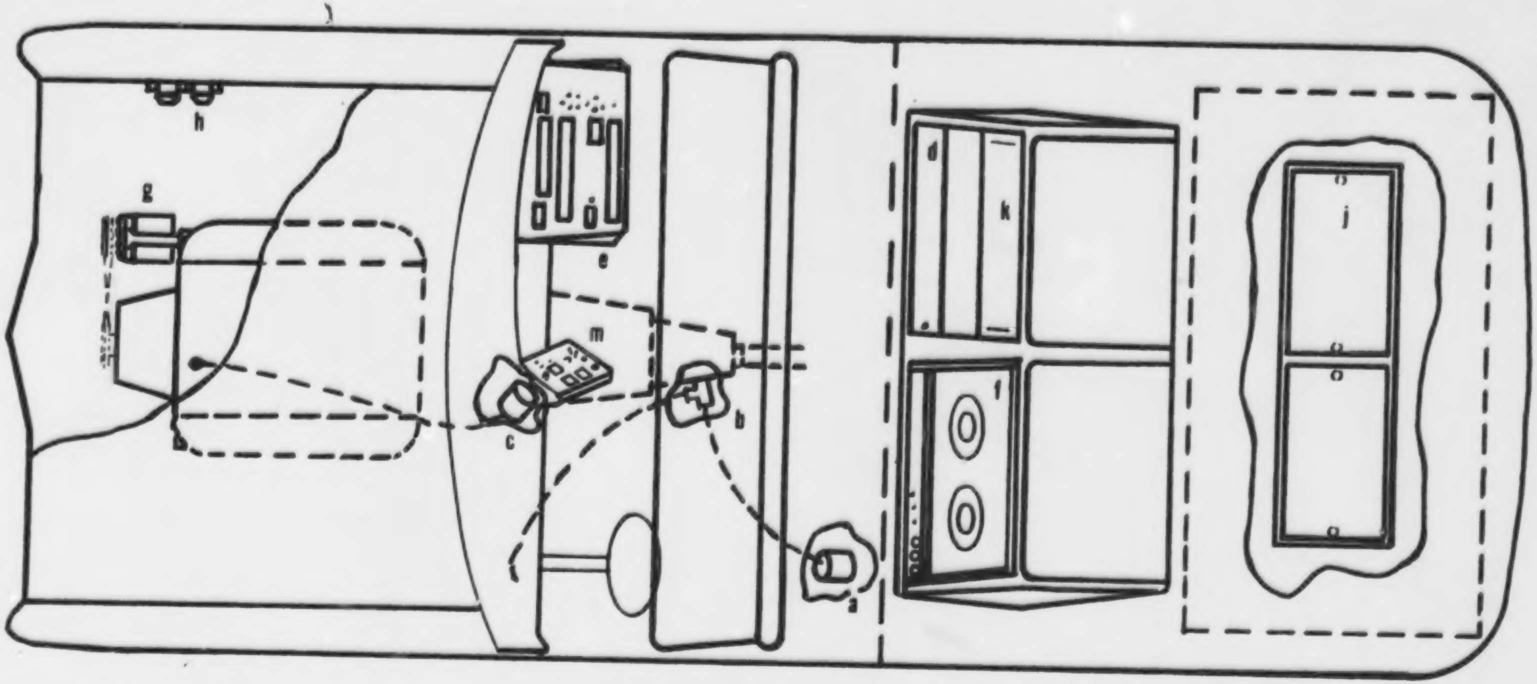
b. Amplified and converted the manifold vacuum analog signal to a digital format equivalent to the manifold vacuum in inches-Hg vacuum with a full-scale capability of 30.0 inches-Hg

c. Generated digital time-of-day data from a 1-MHz clock oscillator source. The clock was also used to control internal logic functions

d. Provided the digital manifold vacuum and time-of-day data to the remote control/display unit for display

e. Received the digitally-coded thumbwheel data from the remote control/display unit

f. Time-multiplexed the time-of-year, time-of-day, fleet, speed, manifold vacuum, weather, road type, segment, trip, and route digital data into a 27-character binary-coded decimal (BCD) serial format and presented these data to the magnetic tape recorder write data input lines once each second for data recording



a. Speed Transducer

b. Speedometer Tee Adaptor

c. Manifold Vacuum Transducer

d. Data Acquisition Unit

e. Control/Display Unit

f. Magnetic Tape Recorder

g. Instrument Alternator

h. Regulator

j. 12 VDC Batteries

k. 115 VAC Inverter

m. Power Control Monitor

Figure 3-2 Instrumentation Component Locations, VOS Vehicles

g. Received the read-back data from the magnetic tape recorder once each second, de-multiplexed these data, and provided them to the control/display unit for display

h. Processed and generated all system control signals for starting and stopping the data acquisition functions.

The remote control/display unit was dash-mounted on the passenger side of the vehicle front seat for operation by the instrument system operator. This unit, whose panel is shown pictorially in Figure 3-3, performed the following functions:

a. Provided NIXIE tube numerical display of the hours, minutes, and seconds time-of-day data, the manifold vacuum data, and a selectable 9-digit field of read-back data. The read-back data were used by the instrument system operator for real-time comparison with the data being written on magnetic tape

b. Provided a three-position rotary switch for selecting the desired 9 (of 27) digits of read-back data for display on the read-back NIXIE indicators

c. Provided digital thumbwheel switches for manually coding the day, fleet, weather, road, segment, trip, and route data

d. Provided a toggle switch for manually overriding the contents of the fleet thumbwheel switches. This override presented 3 digits of zeros (000) to the digital multiplexer and was used when the chase vehicle was not following another vehicle.

e. Provided a thumbwheel switch, a run/hold toggle switch and 6 push-button switches for manually setting the system clock to any desired time of day.

f. Provided system status indicators to indicate stopping or starting of data acquisition, parity-error detection, system write status, and end-of-tape sensing

g. Provided push-button switches for starting and stopping data acquisition, resetting the DDAS, resetting the parity error indicator, and writing end-of-file characters on magnetic tape.

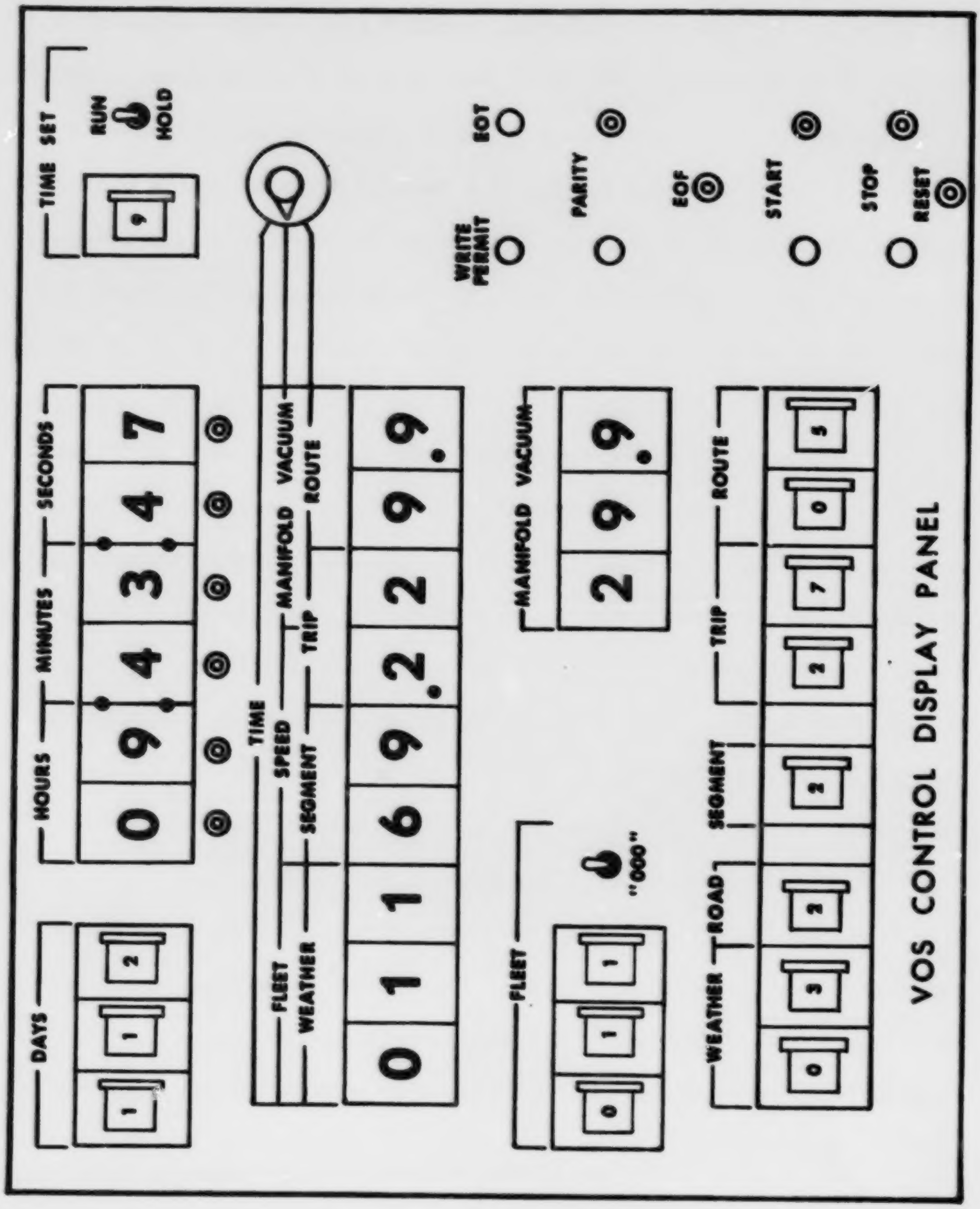

DAYS
HOURS
MINUTES
SECONDS
TIME SET
RUN
HOLD
0 9 4 3 4 7
1 1 2
9
TIME
FLEET
WEATHER
SPEED
SEGMENT
TRIP
MANIFOLD VACUUM
ROUTE
0 1 1 6 9 2. 2 9 9.
WRITE PERMIT
EOT
PARITY
EOF
START
STOP
RESET
MANIFOLD VACUUM
2 9 9.
FLEET
"000"
0 1 1
WEATHER
ROAD
SEGMENT
TRIP
ROUTE
0 3 2 2 2 7 0 5
VOS CONTROL DISPLAY PANEL

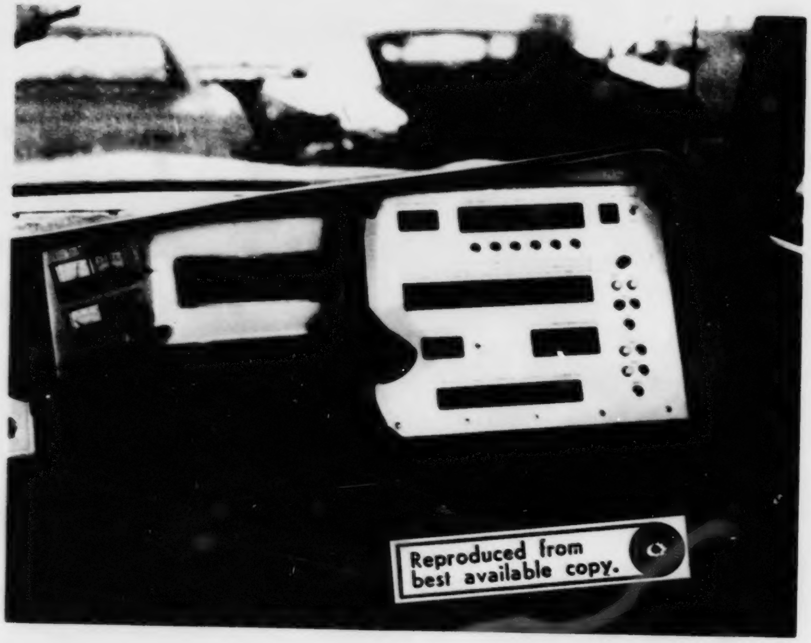
Figure 3-3

The DDAS included a 7-track, 200-BPI, IBM-compatible, synchronous digital magnetic tape recorder which received, once each second, 27 characters of binary-coded-decimal (BCD) data in a serial format from the data acquisition unit multiplexer. The 27-character multiplex was continuously written on magnetic tape and immediately read back and sent to the data acquisition unit for processing and display on the remote control/display unit. The locations of the data acquisition unit, the control/display unit, and the magnetic tape recorder are shown pictorially in Figure 3-2.

Figure 3-4 shows the remote control/display unit as it was installed on the chase-vehicle dash. The unit was provided with an integral light hood and night light necessary for viewing the panel under all ambient light conditions. Figure 3-5 shows the data acquisition unit and the magnetic tape recorder installed in racks in the rear of the vehicle. Note the immediate accessibility of the circuit cards in the acquisition unit and recorder. Figure 3-6 shows a rear view of the instrument racks containing the acquisition unit and the recorder.

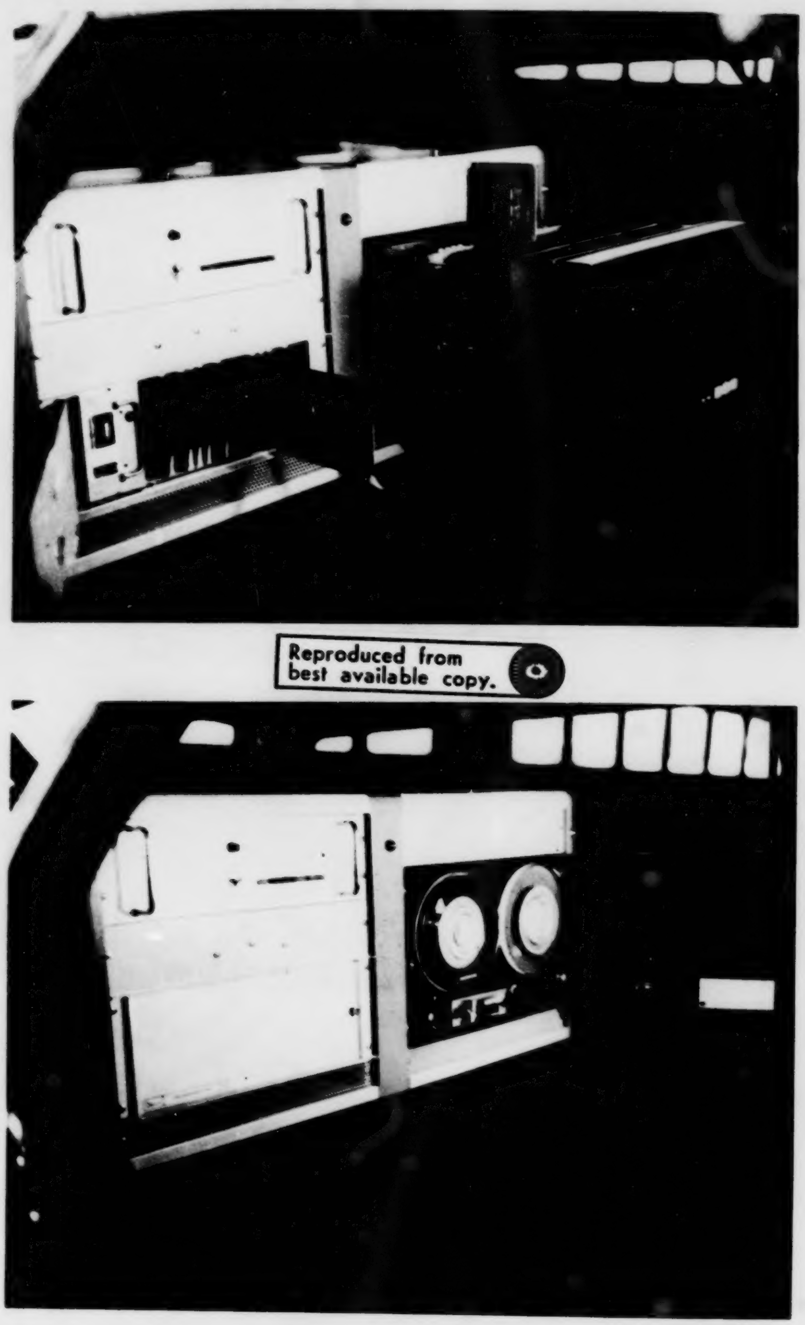
3.2.4 Instrument Power Subsystem

Power for operating the data acquisition system and system transducers was provided by the Instrument Power Subsystem, shown functionally in Figure 3-1. Primary power for the instrument system was supplied from an additional 12-VDC 135-AMP alternator mounted in the chase-vehicle engine compartment and driven by the vehicle engine. This alternator provided power for operating only the instrument system. The alternator output was regulated and supplied power to two 12-VDC 135-Amp-Hour batteries in parallel, providing a stable 12-Volt power source. Output



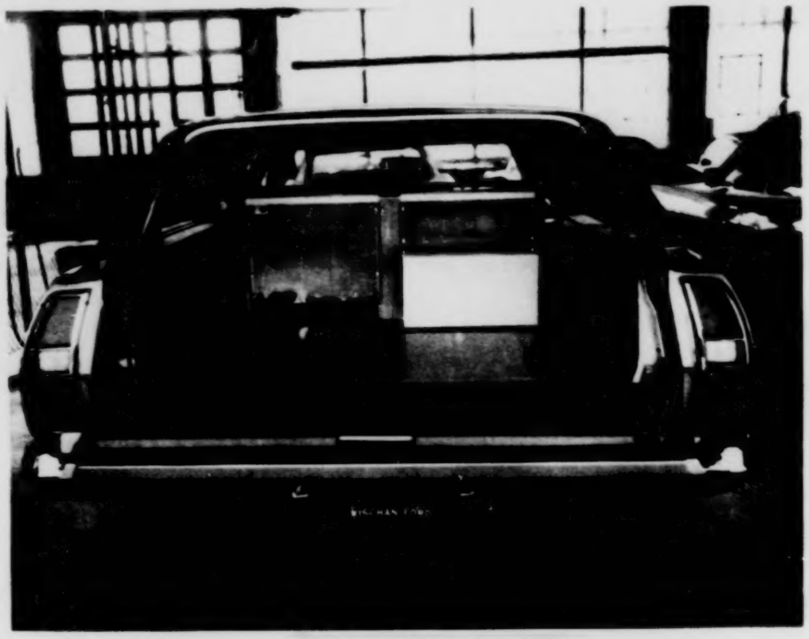
Reproduced from best available copy.

Figure 3-4 Control/Display Panel and Power Control Unit Installed on the VOS Vehicle dash



Reproduced from
best available copy.

Figure 3-5 Data Acquisition Unit, Magnetic Tape Recorders, and 115 VAC Inverter Mounted in VOS Vehicle Rear deck. (a) Accessibility of Electronic Circuit Cords
(b) Ready for Survey Operations



Reproduced from best available copy.

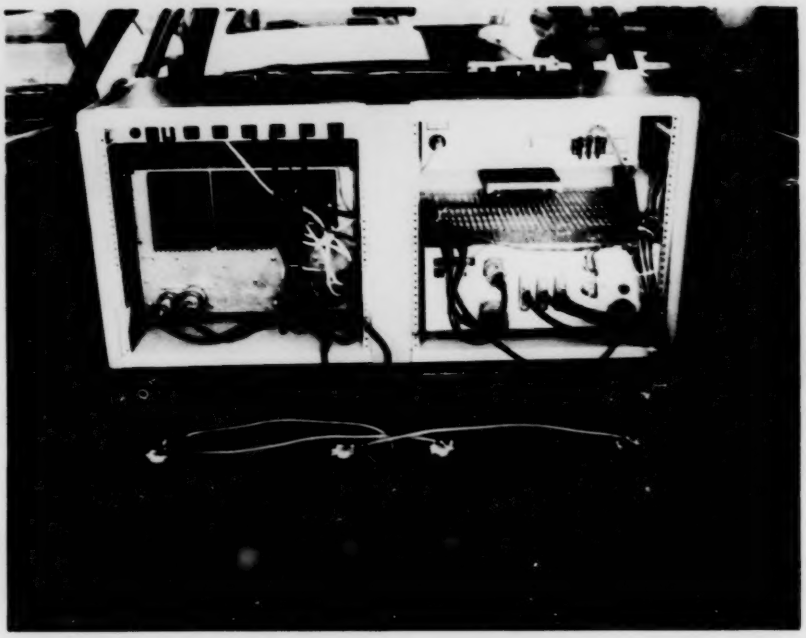


Figure 3-6 Rear of Instrument Racks Containing the Data Acquisition Unit, Magnetic Tape Recorder, and Inverter
(a) Ready for Survey Operations
(b) Access to System Cables and Batteries

from the 12-VDC alternator/battery source was supplied to a DC-to-AC inverter which provided 115-VAC, 500-VA power.

Both the 12-VDC and 115-VAC power were controlled by the Power Control/Monitor Unit before being supplied to the instrument system. The Power Control/Display Unit panel is shown pictorially in Figure 3-7. This panel provided meters for monitoring the system 12-VDC and 115-VAC power buss voltages and battery-charging current. The panel also contained a 4-position main power rotary switch which controlled the application of various forms of power to the instrument system during survey operations.

Controls for both electrically and pneumatically calibrating the manifold vacuum transducer were provided. The necessary adjustment potentiometers and switches for electrically balancing and spanning the manifold-vacuum transducer and signal-conditioning electronics are in the upper right-hand corner of the panel. A two-position manual valve and a calibration port are installed in the lower portion of the panel for providing a pressure-calibration source input to the manifold-vacuum transducer.

The locations of the power system alternator, regulator, batteries, 115-VAC inverter, and control/monitor unit, as they are installed in the chase vehicle, are shown pictorially in Figure 3-2. The instrument system alternator mounted in the chase-vehicle engine compartment is shown in the center of Figure 3-8, and its companion regulator is mounted in the lower left corner of the same figure. The instrument system batteries were mounted as shown in the lower half of Figure 3-6b and were concealed beneath the vehicle rear-floor deck as shown in Figure 3-6a. The 115-VAC inverter was installed

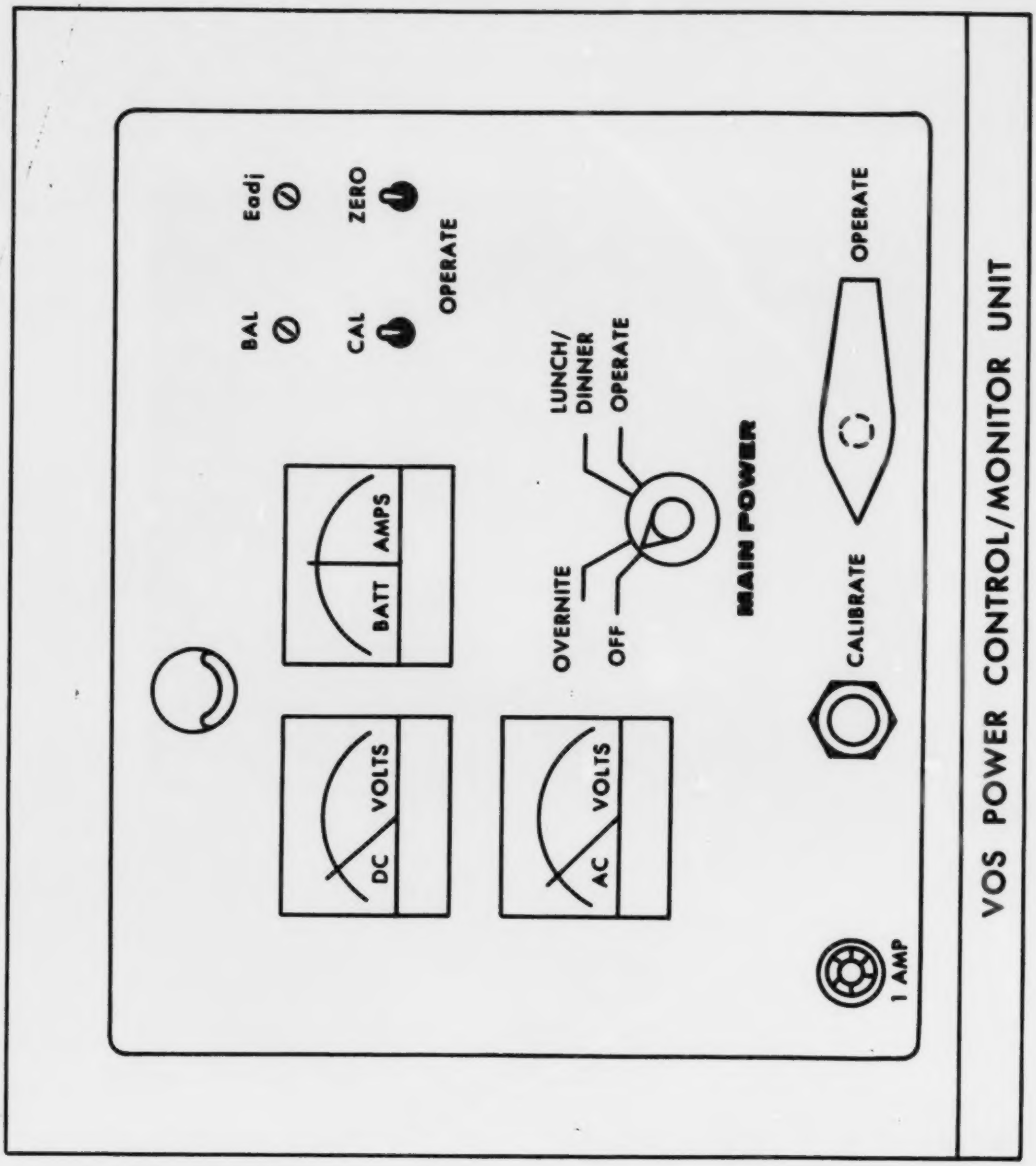
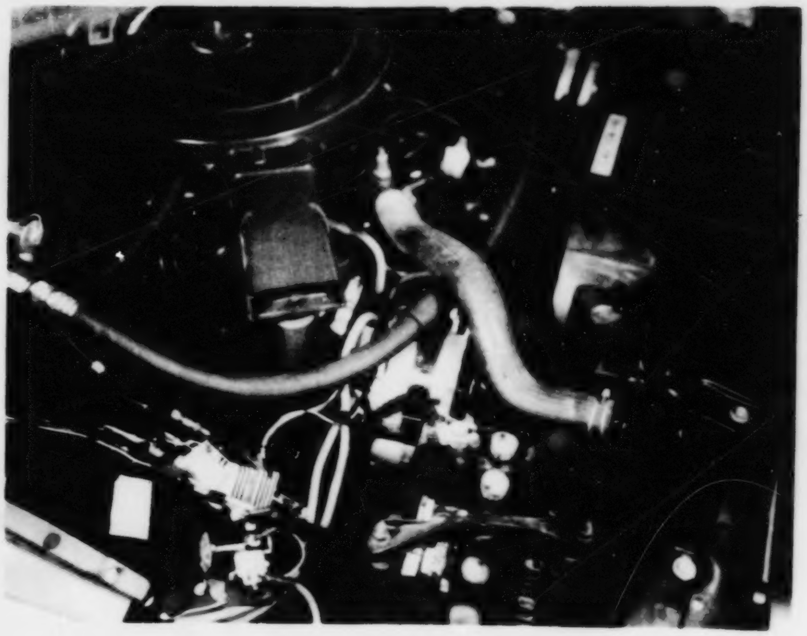

VOS POWER CONTROL/MONITOR UNIT
DC VOLTS
AC VOLTS
BATT AMPS
BAL
Eadj
CAL
ZERO
OPERATE
LUNCH/DINNER
OPERATE
OVERNITE
OFF
MAIN POWER
CALIBRATE
OPERATE
1 AMP

Figure 3-7



Reproduced from
best available copy.

Figure 3-8 Instrument System Alternator and Regulator Installation in a VOS Vehicle

in the rear instrument rack above the data acquisition unit, as shown in Figure 3-5. The power control/monitor unit, installed for instrument operator viewing on the vehicle dash, is shown in the left hand side of Figure 3-4.

3.3 SURVEY ROUTE DESIGN

This section discusses the approach used in designing survey routes over which vehicle operating data were collected. The approach relies on SDC-published data describing vehicle-use patterns for the various cities.

3.3.1 Route Design Objectives

Four general objectives were prescribed in the formulation of a survey route. These objectives were:

- The survey routes should be representative of vehicle usage for a particular city
- Data published in SDC's reports should be used as design guidelines wherever applicable
- The route should provide an opportunity for continuous data collection
- For logistic reasons, a survey route should be driveable in an 8-hour work shift.

SDC data indicated that vehicle usage, characterized by an evaluation of some 27,000 trips in the five cities, cannot be categorized into simple, well-described daily-use patterns. The patterns found to be "typical" actually represented a small percentage of all patterns.

SDC-defined trip descriptors such as start time, trip and segment distance, elapsed time, average speed, number of stops (idles), road type, and trip purpose were scrutinized to determine existing relationships. By analyzing the relationships between descriptors and identifying the predominant trends, a method for developing a route model evolved that had applicability to each city.

3.3.2 Route Design Factors

The following factors (trip descriptors) were considered in the development of a route model for each city:

- Number of Trips
- Length of Trips
- Road Types
- Purpose of Trips
- Day of Week
- Time of Day

Relationships between these factors are shown in Figure 3-9. Generally speaking, functional relationships between factors which could be defined numerically were incorporated directly into the route-model structure. One of the factors, purpose of trip, could not be mathematically related to other factors and was accounted for by considering the direction of travel when mapping out a survey route.

3.3.3 Route-Model Structure

Route models for each city were designed so that the relationships exhibited in Figures 3-10a and 3-10b were comparable between the original SDC data and the route model. The relationship shown in Figure 3-10c is accounted for in the data processing program, as discussed later in this report.

The route model was structured initially by the number of trips of various lengths. Trips were classified by trip distance and placed into the categories shown in Table 3-1. Trips over 27 miles in length were

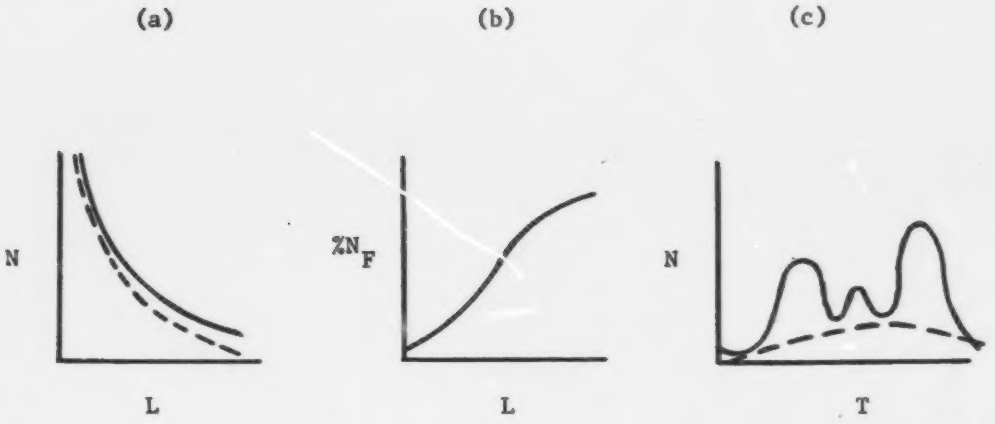
	Length of Trip	Road Type	Purpose of Trip	Day of Week	Time of Day
Number of Trips	A	B	A	B	A
Length of Trips		A	C	B	C
Road Type			C	C	C
Purpose of Trips				A	A
Day of Week					B

A = Major Relationship

B = Minor Relationship

C = No Definite or Important Relationship

Figure 3-9 Relationships Between Factors Affecting Route Design



N = Number of Trips

L = Length of Trips

$\%N_F$ = Percent of Trips with Freeway Segment

T = Time of Day (From Time = 0000 to 2359)

——————— = Weekdays

— — — — = Weekends

Figure 3-10 General Form of Trip Descriptor Functional Relationships

Table 3-1

Typical Route Model Structure For Weekdays

Trip Distance Interval (Miles)	Number of Trips (Total)	Number of Trips (Factored)	Mean Length (Miles)	Total Length (Miles)	% Trips With F Segments	Number of Trips With F Segments	F Mileage Factor	Freeway Miles
0 - 3	1539	11	1.5	16.5	3	0	.64	0.0
3 - 6	695	5	4.5	22.5	16	1	.64	2.8
6 - 9	365	2	7.5	15.0	45	1	.64	4.8
9 - 12	280	2	10.5	21.0	66	1	.64	6.7
12 - 15	194	1	13.5	13.5	76	1	.64	8.6
15 - 18	146	1	16.5	16.5	82	1	.64	10.6
18 - 21	134	1	19.5	19.5	87	1	.64	12.5
21 - 24	82	1	24.0	24.0	94	1	.64	15.4
24 - 27	64							
		24		148.5		7		61.4

eliminated. This distribution of trips was factored by dividing the number of trips in each interval by a least common denominator. The least common denominator was defined to be the number of trips in the least populated interval or group of intervals. The factored number of trips in each interval was then multiplied by the mean trip length for that interval and these products summed to obtain the total length for the model route.

The percentage of trips with freeway segments within each distance interval was determined from the SDC data. These percentages were applied to the number of trips in each interval to obtain the desired number of trips with freeway segments. An overall freeway-mileage factor, based on the number of miles actually driven on freeways as a percentage of the total mileage, was then used to determine the desired length of freeway segments. The total number of trips, total route length, number of trips with freeway segments, and the freeway mileage as a percent of the total route mileage were then checked against SDC's findings. Minor adjustments, made on individual trips to align the overall route characteristics with SDC's findings, were necessitated by the rounding-off inherent in the process.

This approach yielded unique weekday and weekend route models by applying the appropriate basic trip information. At this point the following four route-design factors were accounted for in the structure of the route model:

- Number of trips
- Length of trips
- Road types
- Day of week (weekday or weekend).

Route-model design parameters were then correlated with the SDC values to ensure compatibility. The results are shown in Tables 3-2 and 3-3 for weekday and weekend routes, respectively.

The two remaining design factors to be considered, "Time of Day" and "Purpose of Trips", will be discussed in the following section.

3.3.4 Survey Route Design

The route-model structure shown in Table 3-1 exemplifies the distribution of trip characteristics associated with a typical weekday route for most cities. Route models for weekend application were similar in composition, with a general tendency toward a larger percentage of shorter trips. However, comparison of the route models for weekday and weekend application revealed that approximately 80% of the individual trips were common to both models. This fact facilitated the use of the same road sections for both weekday and weekend survey routes in any given area. Trips not common to both routes were located in the trip sequence for ease of inclusion or exclusion depending on the day of the week in which operations were being conducted. Table 3-4 presents the basic statistics on the survey routes designed for each of the cities. Detailed information on the structure of the individual routes is included in Appendix B.

Predominant in each city was the occurrence of the "home-to-work" trip during the 0600-0859 time slot and "work-to-home" trip in the early evening hours, as shown in Figure 3-11. The direction of travel for the survey vehicles was thus controlled with these factors in mind. Each base of operations (start point for survey operations) was located approximately 15-20 miles from the downtown sections. The survey vehicles

Table 3-2

Correlation of Trip Length Distribution - Weekday Routes

Trip Length, Miles	Los Angeles		Houston		Cincinnati		Chicago		New York	
	Actual	Model	Actual	Model	Actual	Model	Actual	Model	Actual*	Model
0-3	1539	11	743	9	1200	11	1824	11	2679	14
3-6	695	5	431	5	613	5	795	5	1070	5
6-9	365	2	307	4	396	3	493	3	603	3
9-12	280	2	215	3	298	3	315	2	352	2
12-15	194	1	159	2	162	1	222	1	201	1
15-18	146	1	108	1	90	1	169	1	100	1
18-21	134	1	52	1	76	1	108	1	150	
21-24	82	1	28		38		101	1	96	1
24-27	64		13	0	21	0	67		100	
r	0.998		0.996		0.995		0.998		0.999	

* Taxi trips factored out of totals. SDC's trips were defined as "key-on to key-off" operation which resulted in successive fare taxi trips of unusually long mileage. These trips were not comparable to normal passenger car data and were therefore deleted prior to route model construction.

Table 3-3

Correlation of Trip Length Distribution - Weekend Routes

Trip Length, Miles	Los Angeles		Houston		Cincinnati		Chicago		New York	
	Actual	Model	Actual	Model	Actual	Model	Actual	Model	Actual*	Model
0-3	658	14	414	17	680	16	950	19	1012	17
3-6	270	5	131	5	285	7	298	6	309	5
6-9	101	2	75	3	122	3	141	3	166	3
9-12	40	1	42	2	75	2	95	2	80	1
12-15	38	1	40	2	61	1	51	1	38	1
15-18	29	1	27	1	29	1	33	1	29	1
18-21	23	1	15	1	14		30	1	12	
21-24	15	1	9		8	0	20		8	
24-27	14		3	0	0	0	25	0	9	
r	0.997		0.999		0.999		0.999		0.999	

* Taxi trips factored out of totals. SDC's trips were defined as "key-on to key-off" operation which resulted in successive fare taxi trips of unusually long mileage. These trips were not comparable to normal passenger car data and were therefore deleted prior to route model construction.

Table 3-4

Survey Route Design Characteristics

City	Number Of Routes	Average Route Mileage	Average Freeway Mileage	Percent Freeway Mileage	Overall Percent Freeway Mileage
Los Angeles	4 Weekday	149.82	62.05	41.41	41.85
	4 Weekend	144.05	62.05	43.08	
Houston	2 Weekday	162.22	53.50	32.98	32.54
	2 Weekend	156.35	49.08	31.39	
Cincinnati	1 Weekday	143.15	35.40	24.79	23.51
	1 Weekend	129.15	26.00	20.13	
Chicago	2 Weekday	157.70	42.32	26.84	25.22
	2 Weekend	151.60	31.88	21.03	
N. Y. City	2 Weekday	143.25	46.82	32.68	32.05
	2 Weekend	114.55	34.48	30.10	

Purpose of Trip	TIME OF DAY 0600 - 0859	0900 - 1129	1130 - 1329	1330 - 1629	1630 - 1829	1830 - 2059	% of Total Trips for Each Purpose
WORK	80.5%	21.2%	29.2%	16.7%			94.5
BUSINESS	6.1%	47.5%	24.2%	25.8%			86.5
SHOPPING	6.7%	15.3%	29.2%	22.2%	25%	30.2%	95.5
RECREATION					11.4%	24.3%	60
HOME		8.3%	12.0%	28.3%	55.7%	38.7%	82.5
% of Total Trips in Each Time Slot	93.3	92.3	94.6	93	92.1	93	

Figure 3-11 Distribution of Trips by Time of Day and Purpose of Trip (Weekdays)

were generally directed toward the center of town during the early morning time slots, and in an outbound direction during the early evening time slots. It must be recognized that strict adherence to these traffic-direction objectives was not feasible and probably not desirable, since the relationships existing between the two factors cannot be absolutely categorized with respect to direction of travel.

Upon determining all the pertinent trip characteristics and arranging trips into a sequence, the survey route was placed on a detailed street map. In general, each route originated in the suburbs, progressed toward the central city, and returned to the suburbs at least twice during the course of the route. This double-loop system utilized different roads on each half of the route and usually oriented the vehicle in the direction of the majority of traffic during both the morning and afternoon peak hours. That is, since both directions of travel on a given route could not be covered simultaneously, it was judged to be of greater value to obtain operating data on the majority of the traffic.

Each mapped-out route was transcribed into a route directory which provided the surveyors with all the necessary information for driving the route. Route directories supplied details on the following items:

- Route number
- Starting location
- Specific names of roads
- Direction of turns
- Length of segments
- Distance traveled on each street
- Trip number
- Segment number
- Road type code number.

A sample page from a route directory is shown in Figure 3-12.

Road Type	Segm. Number	Trip Number	Segment Length (Miles)	Description	Unit Length (Miles)
				Start at Roscoe Blvd. and Orion	
N-1	1	1	1.45	East on Roscoe Boulevard	0.40
				Left on Columbus Avenue	0.50
				Right on Parthenia Street	0.25
				Left on Noble Avenue	0.30
				Stop at Rayen Street	
N-1	1	2	2.50	Straight on Noble Avenue	0.25
				Right on Nordhoff Street	0.70
				Left on Terrabella Street	1.55
				Right on G.S. 5 Freeway	
F-2	2	2	8.20	G.S. 5 Freeway	8.20
				Exit Burbank Boulevard	
N-1	3	2	2.60	Right on Burbank Boulevard	0.90
				Left on Keystone Street	1.30
				Right on Oak Street	0.40
				Stop at Naomi	

Figure 3-12 Route Directory Sample Page

Consideration was given to traffic density factors during data processing. The original objective was to weight the vehicle operations data to account for the number of vehicles in the traffic flow pattern which were operating in a manner similar to that of the survey vehicle. After contacting traffic engineers to obtain traffic density data, it was concluded that the available information was not well suited to our needs for the following reasons:

- The statistics usually presented traffic density as the number of vehicles passing a point per unit time
- The number of vehicles passing a given point per unit time decreases under very heavy traffic conditions
- Traffic volume data often included traffic in both directions
- Peak-hour and peak-month traffic volumes are of most importance to the traffic engineers and generally were the only form in which such data were published
- Traffic volume data were often not available for capillary (low-volume) streets
- Some available data were up to 10 years old.

SDC-published data, in the form of number of trips versus time of day, were judged to be applicable for the purpose of weighting the vehicle-operation data. Distributions of trip start times for fifteen-minute intervals provided weighting factors for weekday and weekend use for each city. The actual values used for traffic density weighting are given in Appendix C.

3.4 DATA COLLECTION OPERATIONS

This section discusses the procedures and schedule of operations associated with the data acquisition phases of the program.

3.4.1 Training of Personnel

A personnel training program was initiated prior to completion of the instrumentation of the survey vehicles. Instructions in the application of the chase-car technique, operation of the DDAS, manual input of data, tape handling and labeling procedures, and general operating procedures were presented. Four crews, consisting of two men each, were involved in the training program.

Three forms of the chase-car concept were evaluated. One method was based on maintaining a constant distance between the survey vehicle and the automobile being followed. The second method employed a constant time delay between the operating events of the two vehicles. The third method combined the attributes of the first two methods by maintaining constant distances at cruise conditions while allowing for a time lag during acceleration and deceleration modes. Selection of the third method was indicated after comparing the strip-chart recordings from the two vehicles. The combination method placed less emphasis on driver reaction time, was less hazardous for the chase vehicle, and produced the most consistent speed/time traces. The road evaluations revealed another important factor: the problem of overcompensation on the part of the chase-car driver, as indicated by erratic speed-time traces. This occurred when the driver of a chase vehicle concentrated on exactly duplicating the operation of the car in front. By instructing the drivers just to follow a vehicle by "floating behind", the speed irregularities were reduced to a minimum.

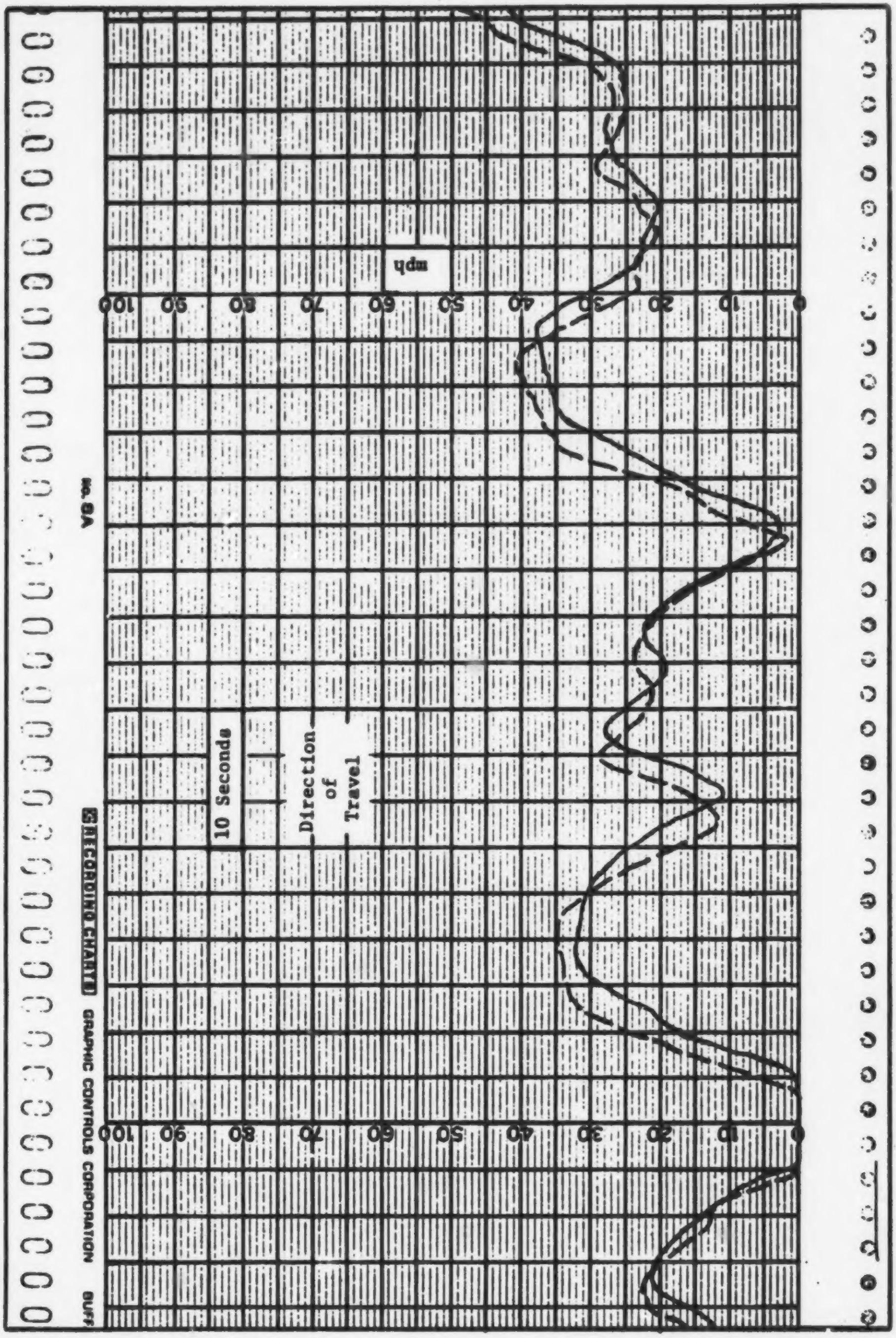
Following a short practice session during which drivers were allowed to familiarize themselves with the chase-car technique, a speed-time comparison was performed. A lead car and a chase-car, both equipped with strip-chart recorders, were operated on a local urban road route. The resultant speed-time traces were superimposed, as illustrated in Figure 3-13. Comparison of the two speed-time traces indicated that the technique under consideration was feasible for simulating vehicle operation in the field.

Operating procedures for the DDAS were explicitly detailed and hence lengthy. A check sheet was drafted to delineate the procedural sequence for the following phases of operation:

- Morning start-up
- Short-break stand-by
- Restart after short break
- Long-Break stand-by
- Restart after long break
- Overnight shut down
- Calibration of speed-sensing system
- Calibration of vacuum-sensing system.

A copy of the instrument system check sheet is shown in Appendix D.

During data acquisition periods the vehicle speed, intake manifold vacuum, and time-clock data were automatically recorded once per second. This information was supplemented by manually-input data defining the route descriptors, type of vehicle being followed, and the existing weather conditions. Numerical codes were developed for these entries. Vehicles were classified into 14 groups by make of vehicle, as shown in Figure 3-14. Weather codes were defined with respect to effect on traffic flow, as presented in Figure 3-15.



——Lead Car
----Chase Car

Figure 3-13

Speed-Time Traces From Lead Car & Chase Car

001 CHEVROLET
Chevrolet, Chevelle, Corvair, Chevy II, Nova, Corvette, Camaro, Vega, El Camino, Monte Carlo

002 FORD
Ford Galaxie, Fairlane, Torino, Mustang, Falcon, Maverick Pinto, Thunderbird, Ranchero

003 PONTIAC
Pontiac, Tempest, Le Mans, GTO, Firebird, Grand Prix

004 PLYMOUTH
Fury, Belvedere, VIP, GTX, Valiant, Barracuda, Swinger

005 BUICK
Buick, Special, Riviera

006 OLDSMOBILE
Oldsmobile, F-85, Cutlass, Toronado

007 DODGE
Coronet, Monaco, Charger, Dart, Challenger, Duster, Polara

008 MERCURY
Mercury, Montego, Cyclone, Cougar, Lincoln Continental, Comet, Meteror

009 CHRYSLER
Chrysler, Imperial

010 AMERICAN MOTORS
Ambassador, Rebel, Rambler, Javelin, AMX, Gremlin

011 CADILLAC
Cadillac, El Dorado

012 OTHER AMERICAN
Checker, Edsel, De Sota, International, Jeep, Kaiser, Nash, Studebaker, Etc.

013 VOLKSWAGEN

014 OTHER FOREIGN CARS
Toyota, Datsun, Jaguar, MG, Porsche, Etc.

NOTE: The fleet switch is to be in the "000" position when no vehicle is being followed.

Figure 3-14 Vehicle Make Code

Visibility:

01 Visibility normal; traffic speed normal

02 Visibility moderately reduced; traffic speed moderately reduced

03 Visibility greatly reduced; traffic speed greatly reduced

Precipitation:

04 Precipitation light (or wet road); traffic speed normal

05 Precipitation moderate; traffic speed moderately reduced

06 Precipitation heavy; traffic speed greatly reduced

NOTES: No amount of smog will be considered great enough to cause traffic speed reductions

Precipitation includes rain, snow, sleet and hail.

Figure 3-15 Weather Codes

3.4.2 Data Collection Schedule

Prior to data collection operations on all driving survey routes, the survey crews circumnavigated the routes for a full day. During this training day the personnel became familiar with the street and freeway systems, traffic light arrangements, and local driving characteristics. After the training period, data collection operations commenced, usually continuing for seven straight calendar days. In this manner it was possible to obtain vehicle operating data for the five weekdays and two weekend days without repetition of any one day.

Two-man crews, consisting of a driver and a navigator (system operator), were used on a two-shift/day basis. This system allowed collection of data nominally from 6:00 a.m. to 10:00 p.m. daily. Of the ten people involved in data collection operations, six were qualified as both driver and navigator (system operator), two were just drivers, and two were navigators only.

Table 3-5 shows the schedule for data collection operations in each of the five urban areas and on the LA-4 route. Operations in Los Angeles commenced five days after the New Year Holiday to avoid the atypical driving patterns expected at that time of year. Similarly, data acquisition efforts in Cincinnati were completed before the Easter weekend to avoid possible holiday traffic influences. No weather conditions severe enough to create prolonged traffic pattern disruption were encountered during the entire schedule.

3.4.3 Operating Technique

Operating procedures in the field were systematically controlled to ensure consistent, high-quality data. The ensuing discussion will

Table 3-5

Data Collection Schedule - Vehicle Operations Survey

Urban Area	Route Number and Application(1)		Reels of Tape Recorded	Date of Survey, 1971
Los Angeles	1	W. D.	20	Jan. 6-8 and Jan. 11-12
	2	W. D.	20	Jan. 6-8 and Jan. 11-12
	3	W. D.	20	Jan. 18-22
	4	W. D.	20	Jan. 18-22
	5	W. E.	8	Jan. 9-10
	6	W. E.	8	Jan. 9-10
	7	W. E.	8	Jan. 16-17
	8	W. E.	8	Jan. 16-17
Houston	9	W. D.	21	Mar. 19 and Mar. 22-25
	10	W. D.	20	Mar. 19 and Mar. 22-25
	11	W. E.	8	Mar. 20-21
	12	W. E.	8	Mar. 20-21
Cincinnati	13	W. D.	20	April 1-2 and April 5-7
	14	W. E.	8	April 3-4
Chicago	15	W. D.	25	April 13-16 and April 19
	16	W. D.	20	April 13-16 and April 19
	17	W. E.	8	April 17-18
	18	W. E.	8	April 17-18
New York City	19	W. D.	20	April 26-30
	20	W. D.	23	April 26-30
	21	W. E.	8	April 24-25
	22	W. E.	9	April 24-25
LA-4	98	O. H.	17	Feb. 16-18
	99	D. H.	17	Feb. 16-18

(1) W. D. = Weekday W. E. = Weekend
O. H. = Off hours D. H. = Defined Hours

delineate the basic sequence of operations for a typical work shift, beginning at approximately 5:45 a.m. Procedures used by the afternoon shift survey crews were nearly identical, beginning with their start time of 1:45 p.m.

The instrumented chase vehicles were started-up about 15 minutes prior to the scheduled commencement of data collection. The DDAS power supply system was energized and proper functioning was verified. The magnetic heads and tape guide rollers on the recorder were thoroughly cleaned and a fresh 1200-foot reel of 1/2-inch tape was mounted.

With the electronics warmed-up, the clock was set to the proper time and started. The speed-measuring circuitry and manifold-vacuum circuitry were electronically calibrated. With real-time data verification capabilities designed into the DDAS, it was possible to check for proper operation of these three circuits by scanning the nixie readouts on the control/display pannel. All manually-operated thumbwheel selector switches were then checked for proper functioning and set at the desired positions for the start of data collection.

The survey crew then proceeded to the survey route starting point, verifying the proper operation of all systems with the vehicle in motion. At this time the tape was rewound to the Beginning-of-Tape marker and data collection operations were started.

The chase-vehicle driver drove the survey vehicle around the prescribed route in accordance with the directions in the survey-route directory. The navigator/system operator supplied verbal instructions to the driver regarding the correct roads to follow and where to make turns.

At the appropriate places along the route, the navigator/system operator reset the trip number, segment number, and road-type selector switches.

During the circumnavigation of the route, the driver used the chase-car technique for following other vehicles. The make of vehicle being followed was recorded with the appropriate code-number selection of the "Fleet" thumbwheel switch. When no vehicles were being followed, the "Fleet" switch was set in the "000" position and the driver continued along the route at a normal pace. While following other cars, the survey vehicle was restricted to operations consistent with the driving regulations and prescribed speed limits for that particular area. While collecting data on certain lengthy road segments, the driver was instructed to follow vehicles for no more than approximately 2 minutes and to alternate lanes, thus sampling a larger variety of the vehicle population.

Approximately every ten minutes the navigator/system operator routed the display selector switch to each position as a check for proper recording and readback of all collected data.

Each reel of magnetic tape was sufficient for about 3½ hours of data collection. At the mid-point of the route, a break was taken. The tape was stopped at this time, rewound, removed, and properly labeled with the following items:

- Date
- City
- Route number
- Trip numbers completed
- Shift number
- Chase vehicle number
- Tape I. D. Number
- Comments.

The same information was recorded in log books at the end of each day by the survey operations supervisors. The log books thus provided a comprehensive inventory of all data collected.

Following the break, the tape recorder heads and rollers were cleaned and a second reel of tape mounted. Data collection then resumed until the survey route was completed, usually requiring about six full hours of data collection per shift. The second tape was removed and labeled and most of the instrumentation sub-systems were shut down. After completion of the morning shift, the clock system remained active to eliminate the necessity for resetting by the afternoon shift survey crew. The afternoon shift began collecting data at approximately 2:00 p.m., using the same operating procedures. Shift starting times were adjusted as required to prevent the break periods from occurring at exactly the same time each day. Under extremely heavy traffic conditions, it was sometimes necessary to use three reels of tape during one shift of data collection.

A few minor electronic and mechanical problems were observed in the field. On these infrequent occasions, the back-up survey vehicle was placed in operation and the problems corrected as rapidly as possible. Among the survey crew members were a mechanic and an electronic technician whose skills enabled the survey operations to remain on schedule at all times. All recorded tapes were logged in by the supervisors and carefully packaged for air freight delivery to Scott's San Bernardino laboratory every three or four days.

3.4.4 Vehicle Operations Survey on the LA-4 Route

As an auxillary task to the basic VOS program, vehicle operating patterns were determined over the LA-4 road route for comparison with the urban Los Angeles (LA-Composite) driving pattern. The LA-4 road route, designed in the late 1960's and located within a 6-mile radius of central Los Angeles, is shown in Figure 3-16. Vehicle operating patterns on the route, during the weekday hours of 9:00 a.m. to 11:00 a.m. and 1:00 a.m. to 3:00 p.m., were intended to typify morning rush-hour driving patterns for central Los Angeles.

Although the surveys of vehicle operating patterns on the LA-Composite routes and the LA-4 route were operationally similar in many respects, there existed certain differences between the two surveys. The studies were similar with respect to the following items:

- Use of chase-car technique
- Survey-vehicle performance capabilities
- Instrumentation systems
- Operating personnel
- Data format
- Data processing program.

Differences between the two studies were primarily associated with the overall scope of operations, route structure, and data collection time periods. Table 3-6 presents the details of these differences. Vehicle operating data were collected during the "defined hours" of 9:00 a.m. to 11:00 a.m. and 1:00 p.m. to 3:00 p.m., and during the "off-hours" of 7:00 a.m. to 9:00 a.m. and 3:00 p.m. to 5:00 p.m. (to provide additional information on the LA-4 route).

1. Start behind County Air Pollution Laboratory.
2. Right on Fifth.
3. Right on San Pedro.
4. Left on Third St.
5. Up ramp to Harbor Fy. South.
6. Exit Harbor Fy. at Exposition.
7. Follow Exposition to Western.
8. Right on Western.
9. Right on Olympic.
10. Left on Santee.
11. Right on Ninth.
12. Left on San Pedro.
13. End just beyond intersection San Pedro and Fifth Street.

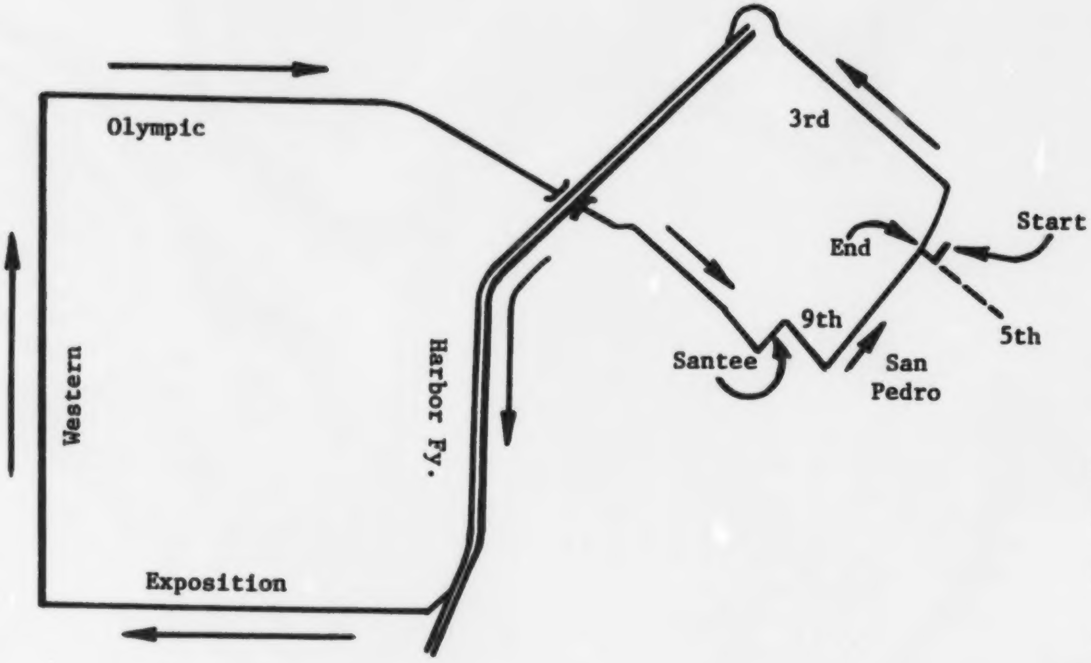

Olympic
3rd
Start
End
5th
9th
Santee
San Pedro
Western
Harbor Fy.
Exposition

Figure 3-16 LA-4 Road Route Description

Table 3-6

Differences Between LA Composite and LA-4 Survey Parameters

		LA Composite	LA-4
1.	Objectives associated with route(s)	To provide a road course over which vehicle operating behavior can be surveyed to determine overall vehicle operating characteristics for metropolitan Los Angeles	To provide a road course that will typify vehicle operating behavior during the morning, peak-hour traffic in Central Los Angeles in the fall
2.	Route Locations	Within 25-mile radius of Central Los Angeles	Within 6-mile radius of Central Los Angeles
3.	Number of Routes Surveyed	4 - Weekday 4 - Weekend	1 - Weekday
4.	Number of Replications per Route	10 - Weekday 4 - Weekend	84
5.	Route Length (nominal)	145 miles	13 miles
6.	Total Survey Mileage (nominal)	7,850	1,100
7.	Survey Time Period	6:00 A.M. to 10:00 P.M., 7 Days Per Week	Defined Hours Were: 9:00 A.M. to 11:00 A.M. and 1:00 P.M. to 3:00 P.M., Tuesday Wednesday and Thursday
8.	Traffic Density Weighting	Traffic density values based on time of day were used to weight results during computer processing	Considered to be self-weighting

The basic results of this investigation are presented in Section 4.0 of this report. A complete discussion of the LA-4 survey and comparison of results with the LA-Composite survey is contained in Reference 10.

3.5 DATA PROCESSING AND ANALYSIS TECHNIQUES

The large volume of data collected during the VOS Program necessitated fast, efficient data processing procedures. The basis for these procedures and descriptions of the various techniques used will be discussed in this section. The initial approach to data processing will be presented first, followed by a discussion of the modifications that were made to the data processing program in Phase II. Descriptions of the final computer programs as well as the computer facilities, are presented. Since data from various geographical locations were processed, techniques were developed to provide indicators of the similarity between the vehicle operating characteristics for the data collected from these different areas.

3.5.1 Data Processing Techniques

The large volume of data collected necessitated highly reliable data acquisition equipment in addition to fast, efficient data processing procedures. The groundwork for successful data processing was established by using a dependable, accurate Digital Data Acquisition System (DDAS) and recording the vehicle operating data on high-quality magnetic tape. Representation of vehicle operating modes (an operating mode is defined here to be a distinct event; i.e. an idle, cruise, acceleration, or deceleration characterized by an initial speed, final speed, and duration) in matrix format required a large-core, fast-operating computer. The procedure to establish the driving modes that represent vehicle operation was the primary task of the data processing effort and will be described in detail in this section.

3.5.1.1 Initial Data Processing Approach

The research nature of this program required that flexible procedures be used in the data processing so that, if evaluation of the results indicated a modification was needed, this could easily be integrated into the data processing technique with as little effort as possible. The preliminary data processing techniques described here were developed such that, after initial processing of some data and analysis of the results, required modifications were easily incorporated to make the results more representative and useful.

As discussed above, the primary objective of the VOS program was to obtain data which could be used to describe the operating characteristics of vehicles in various large American cities. In order that these characteristics be representative of the driving from which the VOS sample was taken, two criteria must be met. First, sufficient information must be recorded so that the manner in which vehicles are driven during each operating mode may be determined. This was made possible by recording vehicle operating data at precise one-second intervals. Therefore, the operating characteristics may be shown at one-second intervals during all of the operating modes. This includes calculating the duration of each mode. Secondly, the frequency of occurrence of the operating modes must be determined. Since each VOS vehicle emulated the operation of only one other vehicle, traffic density weighting factors developed by SDC were applied to the observed mode frequencies to make the data representative of all the traffic.

To fulfill the objectives of this program, time data, data pertaining to vehicle operation, and various auxiliary data were recorded for later analysis. Time parameters were: day of the year, hour, minute, and second. Vehicle operating parameters recorded were: speed, in tenths of a mile per hour; manifold vacuum, in tenths of an inch of mercury guage; and a code indicating the type of vehicle being chased. The auxiliary data consisted of code numbers for: weather conditions, type of road being driven, and route, trip, and segment numbers for each city. Each parameter was sampled once per second, and the data so obtained were recorded in 7-track format at 200 bpi in a 27-character record on magnetic tape. The order in which the data were recorded and the number of characters for each parameter are shown in the following table. The range of possible values for each parameter is also shown.

Parameter	Number of Characters	Range
Day of the year	3	0 to 365
Hour	2	0 to 23
Minute	2	0 to 59
Second	2	0 to 59
Fleet Number	3	0 to 999
Speed	3	0 to 70.0 mph
Manifold Vacuum	3	0 to 30.0 inches of Hg
Weather Type	2	0 to 99
Road Type	1	0 to 9
Segment Number	2	0 to 9
Trip Number	2	0 to 99
Route Number	2	0 to 99
Total	27	

A 27-character record of 9's was used as a special indicator for the end-of-tape mark on each reel.

The primary VOS data for determining representative vehicle operation are obtained from the speed and time parameters. Since a continuous sequence of speeds at one-second intervals is cumbersome to work with and difficult to analyze, a scheme was developed to partition the sequence of speeds into a series of three distinct types of vehicle operating modes. These mode types are: cruises (including idles), accelerations, and decelerations. The distinguishing characteristics of each mode are its initial speed, duration in seconds, and final speed. The initial and final speeds of a mode are used to determine which of the three mode types is appropriate. The mode-selection logic for segmenting a sequence of speeds is shown schematically in Figure 3-17.

These mode criteria may be thought of as follows. Assume the vehicle whose operation is being observed begins cruising at some speed, s. A 0.5-mph band is established on either side of the initial cruise speed s. Successive speeds are then analyzed until a speed is observed to be outside of the 1-mph band. The last speed inside of the band marks the end of the cruise mode and also the beginning of the next mode. A cruise mode was also terminated in the original program when successive speeds differed by more than 0.2 mph. The mode duration is obtained from the difference in the times corresponding to the final and initial speeds.

The mode following a cruise was an acceleration if the cruise ended when a speed exceeded the upper band and was more than 0.2 mph greater

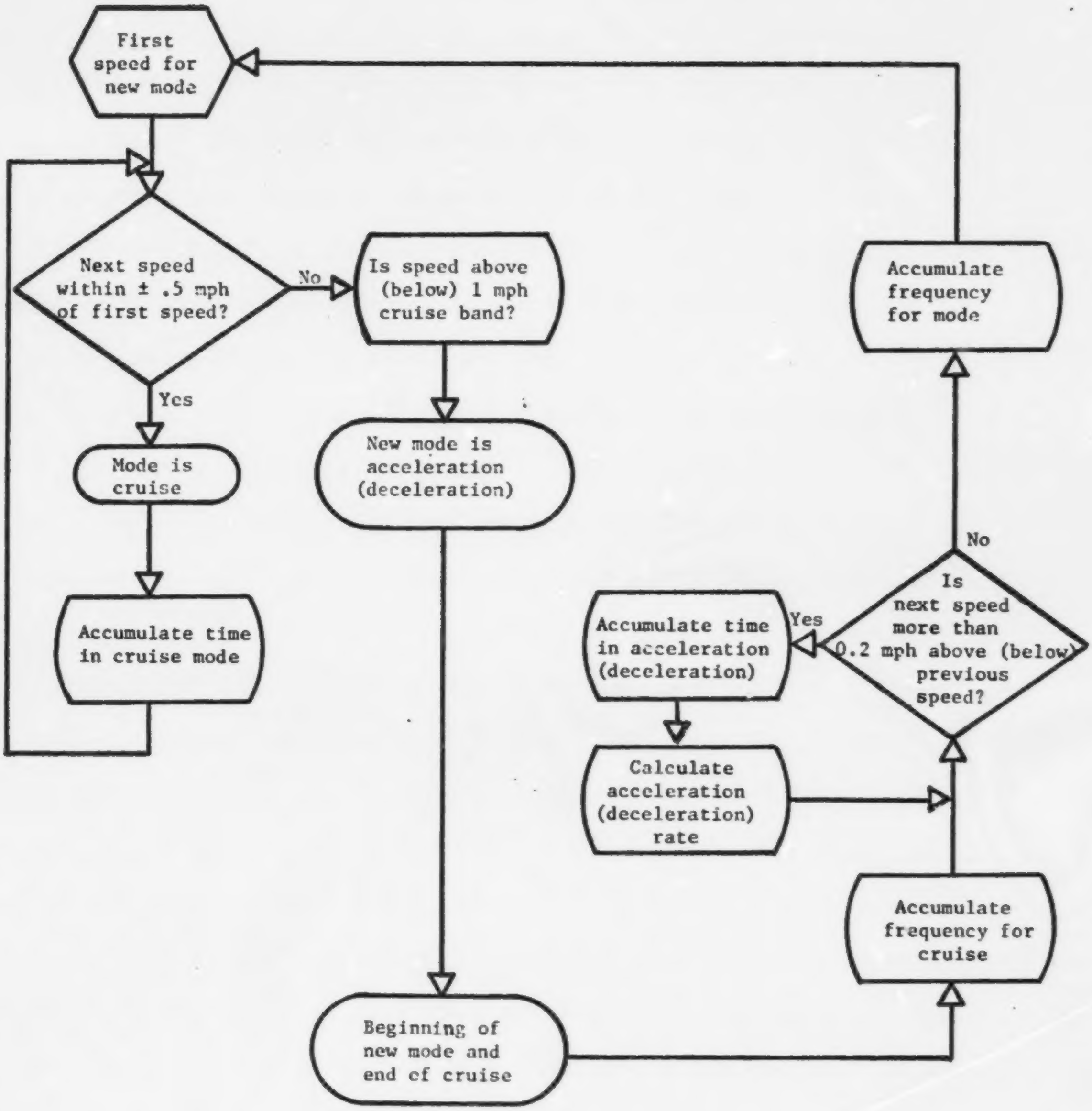
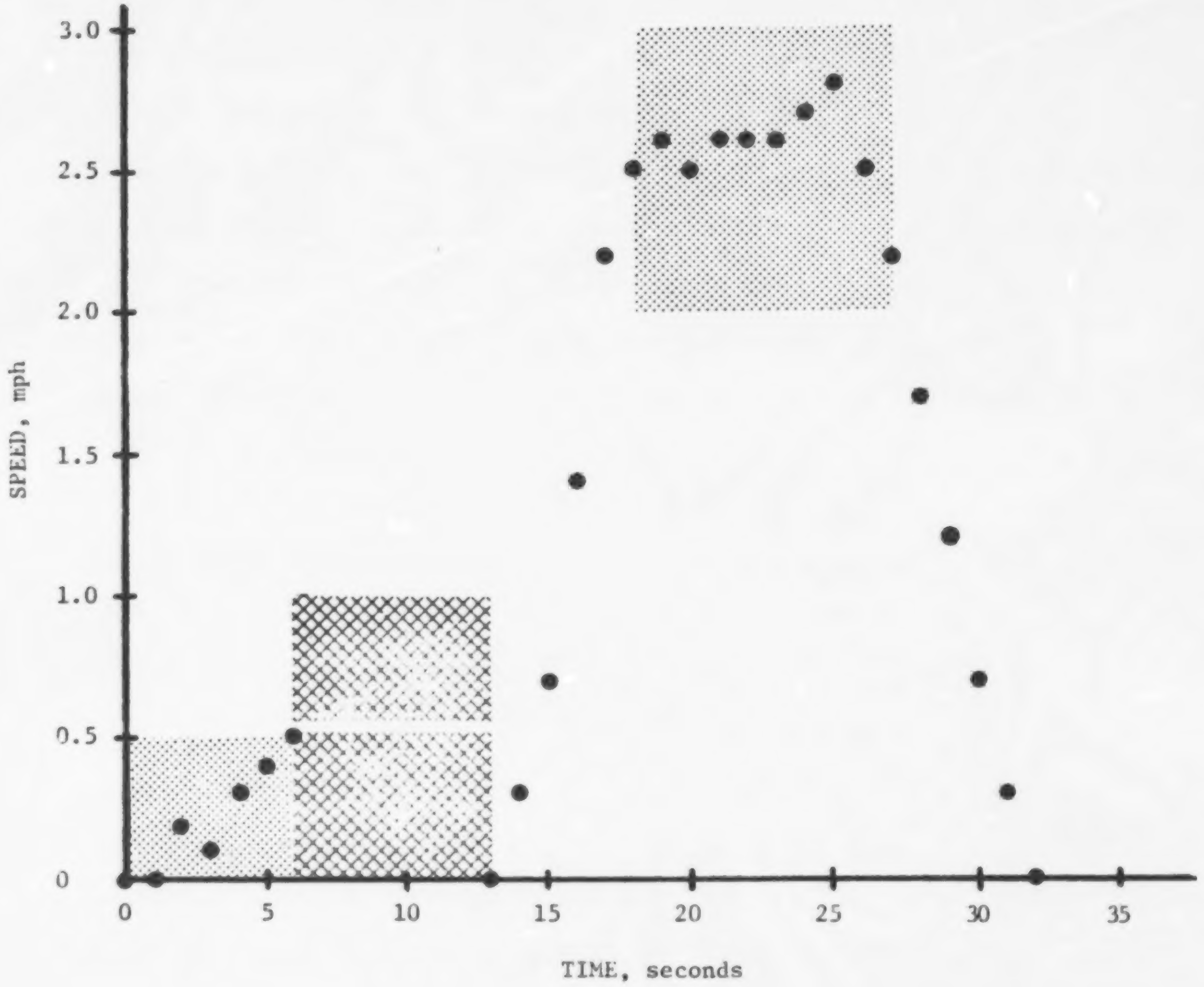

First speed for new mode
Next speed within ± .5 mph of first speed?
No
Yes
Is speed above (below) 1 mph cruise band?
Mode is cruise
Accumulate time in cruise mode
New mode is acceleration (deceleration)
Beginning of new mode and end of cruise
Accumulate frequency for cruise
Is next speed more than 0.2 mph above (below) previous speed?
Yes
No
Accumulate time in acceleration (deceleration)
Calculate acceleration (deceleration) rate
Accumulate frequency for mode

Figure 3-17 Mode-Selection Logic

than the previous speed. The new mode was a deceleration if a speed lower than the lower band was observed and was also more than 0.2 mph less than the preceeding speed. For cases where the 0.2-mph criterion was not met, two successive cruise modes occurred. The final speed of the first cruise became the initial speed of the second cruise and was, therefore, the speed about which the one-mph band was established. Once an acceleration (deceleration) mode had been established, successive speeds were analyzed to determine if each were greater (less) than the preceeding speed by more than 0.2 mph. Failure to meet the 0.2-mph criterion ended the acceleration or deceleration mode. The duration was calculated the same as for the cruise.

Figure 3-18 shows a sequence of speeds to which the previously described technique was applied. The initial speed, final speed, and duration are shown for each mode. Note that the 0.5-mph cruise band for an initial cruise speed of zero (idle) is meaningful only for positive speeds. Deficiencies in the initial program logic described above were identified during the initial processing of LA data and corrected as discussed below.

Applying these mode criteria to a sequence of speeds enables us to reduce a cumbersome list of speeds to a sequence of modes uniquely defined by their initial and final speeds and durations. All that is lacking is a bookkeeping procedure to allow accumulation of a large volume of data. The mode-matrix approach to the representation of vehicle operating data provides the needed procedure. The basis for this technique is a



6 second cruise at 0.25 mph	7 second cruise at 0.25 mph	5 second accel from 0. mph to 2.5 mph	9 second cruise at 2.35 mph	5 second decel from 2.2 mph to 0. mph

NOTE: Shaded area represents ± 0.5 mph cruise band about initial cruise speed.

Figure 3-18 Segmentation of Speed/Time Data Into Modes Using Preliminary Mode Logic

square grid, as shown in Figure 3-19, with initial speed along the vertical axis and final speed along the horizontal axis. The fineness of the grid structure was determined by analysis of our own driving habits and the practicality of working with matrices of reasonable size. This and the speed laws of many states led to the initial and final speed axes being laid out in 70 one-mph grid cells. Each cell thus represents one of the 4900 modes which are possible with this matrix approach. As shown in Figure 3-19, the cells along the diagonal form the cruise modes, the cells above this diagonal are the acceleration modes, and the cells below the diagonal are the deceleration modes.

The master mode matrix, is produced by laying out a time axis as the third dimension of the basic mode matrix, as shown in Figure 3-20. The time axis is laid out in 20 cells as follows: the first 15 cells are each one second wide, the next four cells are each five seconds wide, and cell number 20 includes time durations of 35 seconds and greater.

As the recorded VOS data were processed into modes, the appropriate traffic density weighting factor was added to the frequency for each mode in the time cell corresponding to the mode duration. A master mode matrix was developed for the data collected each time a route was driven. The number in each cell is the cummulative weighted frequency of occurrence of that particular mode for the indicated duration. The master mode matrix thus yields the distribution of time in mode for each mode. This distribution is obtained from the third dimension (time axis) for each mode. Plotting the cell frequencies at the corresponding times shows this distribution graphically. Following the

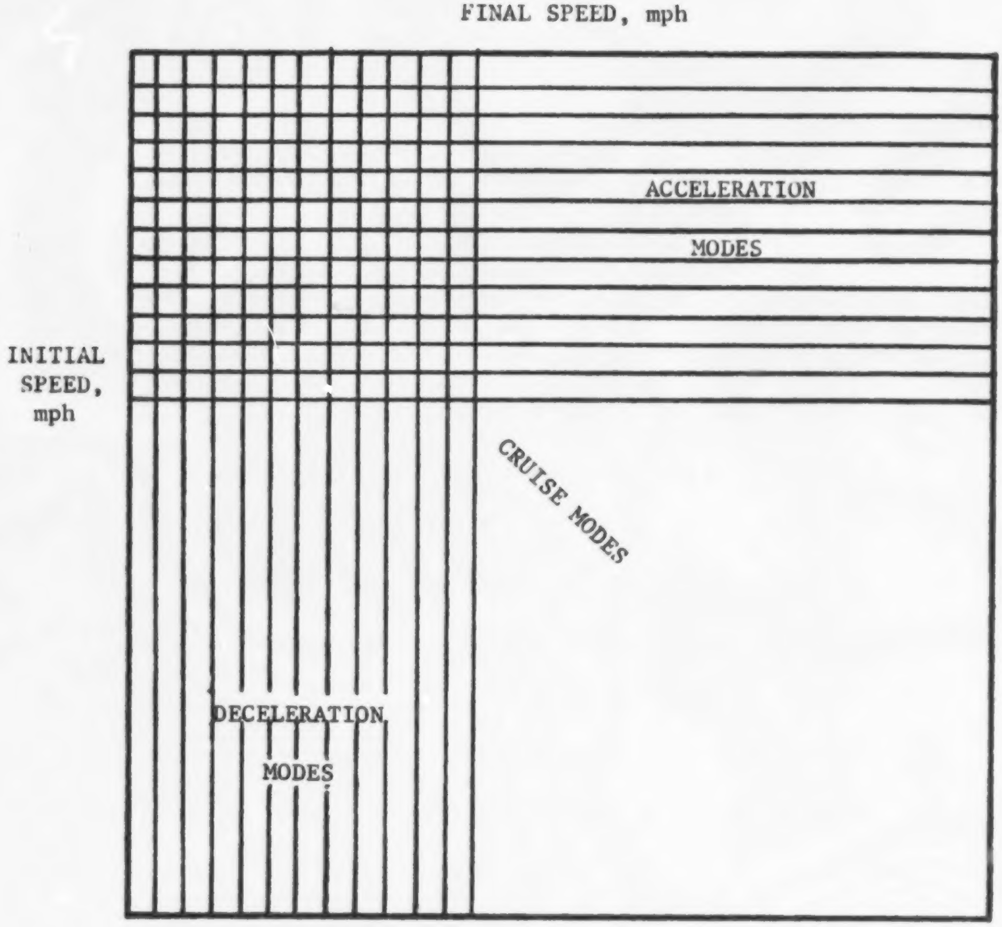
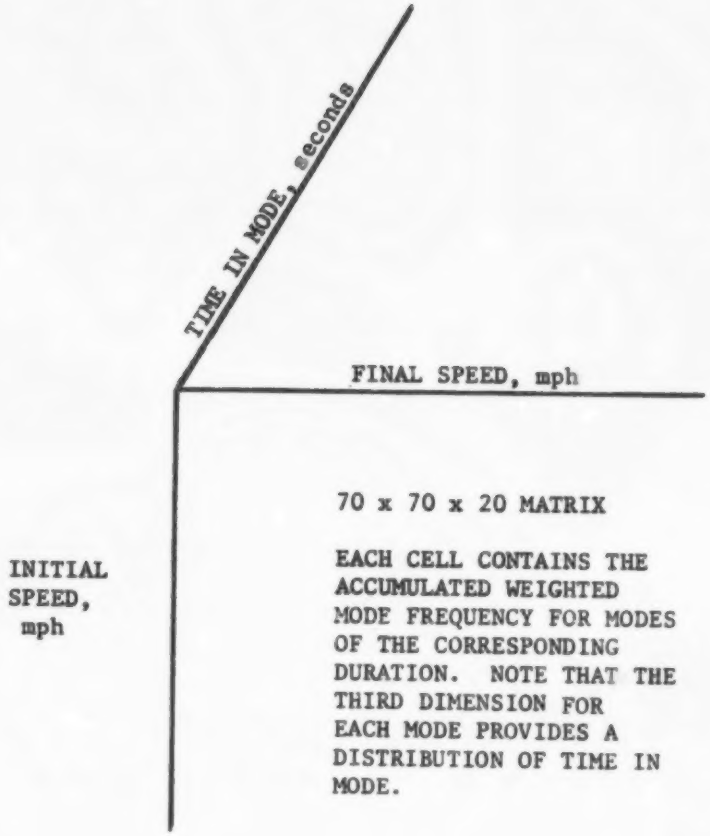

FINAL SPEED, mph
INITIAL SPEED, mph
ACCELERATION MODES
CRUISE MODES
DECELERATION MODES

Figure 3-19 Matrix Representation of Vehicle Operation


TIME IN MODE, seconds
FINAL SPEED, mph
INITIAL SPEED, mph

70 x 70 x 20 MATRIX

EACH CELL CONTAINS THE ACCUMULATED WEIGHTED MODE FREQUENCY FOR MODES OF THE CORRESPONDING DURATION. NOTE THAT THE THIRD DIMENSION FOR EACH MODE PROVIDES A DISTRIBUTION OF TIME IN MODE.

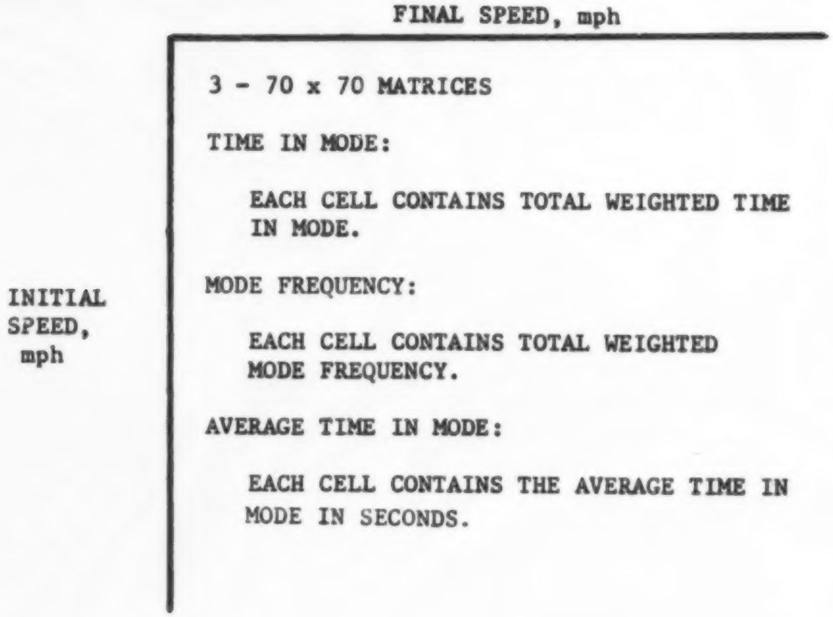
Figure 3-20 Master Mode Matrix

mode analysis of the data for a route replicate, the master mode matrix is used to calculate the total-time-in-mode matrix and the mode-frequency matrix.

The total-time-in-mode matrix, formatted as shown in Figure 3-21, is obtained from the master mode matrix by summing the product of each cell frequency and the time corresponding to that cell for each mode. Each entry in the total-time matrix is thus the total weighted number of seconds of vehicle operation in that particular mode. The mode-frequency matrix, formatted as shown in Figure 3-21, is obtained from the master mode matrix by summing the frequencies in the time-axis cells for each mode. Each entry in the mode-frequency matrix is therefore the total weighted number of times a particular mode is executed.

Division of each entry in the total-time matrix by the corresponding entry in the mode-frequency matrix produces the average-time-in-mode matrix. The average-time-in-mode matrix, also formatted as shown in Figure 3-21, contains the average number of seconds required to execute each mode.

The mode-frequency matrix may be transformed to restore sequence (in a probabilistic sense) to the data. Each row of the mode-frequency matrix represents all modes that have the indicated initial speed. Therefore, by dividing each non-diagonal row entry by the sum of all non-diagonal frequencies for the row, we obtain the conditional probability that the next speed transition will end at the speed indicated by the column heading. This matrix is called the transition-probability matrix and is formatted as shown in Figure 3-22. Note that each row of the transition-probability matrix sums



FINAL SPEED, mph

INITIAL SPEED, mph

3 - 70 x 70 MATRICES

TIME IN MODE:

EACH CELL CONTAINS TOTAL WEIGHTED TIME IN MODE.

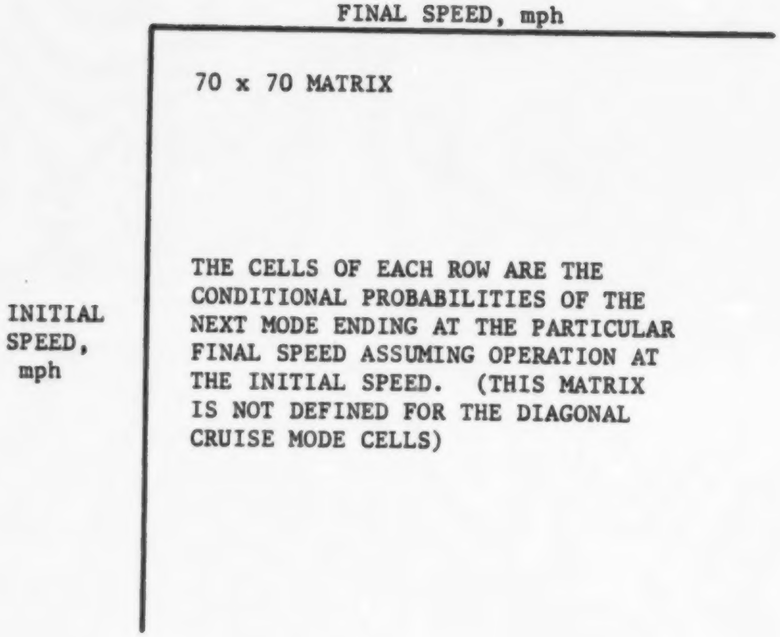
MODE FREQUENCY:

EACH CELL CONTAINS TOTAL WEIGHTED MODE FREQUENCY.

AVERAGE TIME IN MODE:

EACH CELL CONTAINS THE AVERAGE TIME IN MODE IN SECONDS.

Figure 3-21 Vehicle Operation Mode Matrices


FINAL SPEED, mph
70 x 70 MATRIX
INITIAL SPEED, mph

THE CELLS OF EACH ROW ARE THE CONDITIONAL PROBABILITIES OF THE NEXT MODE ENDING AT THE PARTICULAR FINAL SPEED ASSUMING OPERATION AT THE INITIAL SPEED. (THIS MATRIX IS NOT DEFINED FOR THE DIAGONAL CRUISE MODE CELLS)

Figure 3-22 Transition Probability Matrix

to unity, since all (different) final speeds are possible for each initial speed. A sequence of modes may thus be generated with random number sampling based on the transition probabilities.

These four matrices (total time, mode frequency, average time in mode, and transition probability) form the basis for describing vehicle operation and will be referred to as the mode matrices. Together with the development of the master mode matrix, however, auxiliary data are accumulated into several supplementary matrices. The information obtained from these matrices is used in conjunction with the mode matrices to provide an overall description of representative vehicle operation for the observed city.

Each route in a city was composed of a sequence of typical short trips whose lengths are representative of the distribution of trip lengths observed in that city. The trip distance is calculated by numerical integration of the speed/time data. The time required to drive each trip is accumulated as the data are being analyzed. The thumbwheel switch indicating the trip number is sampled once each second and recorded on the magnetic tape so that the end of a trip is noted each time the trip number changes. Dividing the trip distance by the time required to drive the trip yields the average speed for the trip. These data are accumulated by average trip speed, trip distance, and time of day in the 3-dimensional matrix shown in Figure 3-23. The time-of-day slots are indicative of the various traffic conditions that exist throughout the day and are included to provide information on the variability of average speed for trips of the same distance. These time-of-day slots, which are different for weekdays and weekends, are shown in the table below.

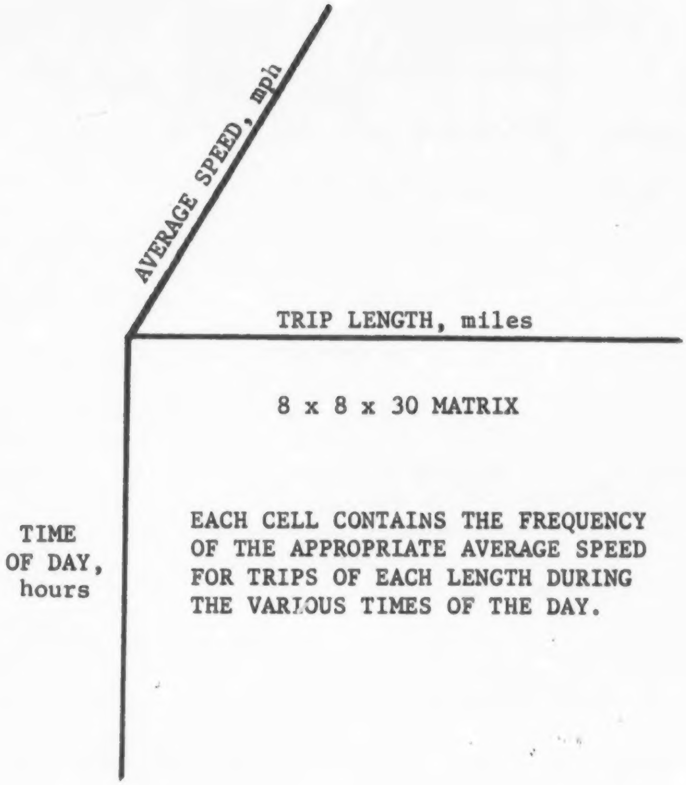

AVERAGE SPEED, mph
TRIP LENGTH, miles
8 x 8 x 30 MATRIX
TIME OF DAY, hours
EACH CELL CONTAINS THE FREQUENCY OF THE APPROPRIATE AVERAGE SPEED FOR TRIPS OF EACH LENGTH DURING THE VARIOUS TIMES OF THE DAY.

Figure 3-23 Matrix of Average Speed Versus Trip Length and Time of Day

WEEKDAYS	WEEKENDS
0000 - 0600 Hours	0000 - 0830 Hours
0600 - 0900 Hours	0830 - 1100 Hours
0900 - 1130 Hours	1100 - 1300 Hours
1130 - 1330 Hours	1300 - 1800 Hours
1330 - 1630 Hours	1800 - 2100 Hours
1630 - 1830 Hours	2100 - 2400 Hours
1830 - 2100 Hours	
2100 - 2400 Hours	

The trip-length axis is partitioned into seven cells, each covering an interval of three miles, and an eighth cell covering six miles, to accomodate trips from 21 to 27 miles. The average speed axis of this matrix covers a speed range from 0 to 60 mph, divided into 20 cells of three mph each. As the data for each trip are analyzed, tally marks are accumulated in the appropriate cells determined by the time of day, trip length, and average speed. This matrix of average speeds for various trips supplements the mode matrices by providing insight into the variability of average speed with trip length and time of day. The time-of-day factor will reflect traffic density influences on vehicle operation.

The acceleration-rate-versus-instantaneous-speed matrix, shown in Figure 3-24, is another auxiliary data matrix of interest. The speed axis is partitioned into 70 one-mph cells. The acceleration-rate axis is composed of 80 one-quarter-mph/second cells between plus and minus 10 mph/second. During the mode analysis of the data for a route replicate, acceleration rates are calculated from every pair of adjacent speeds for all

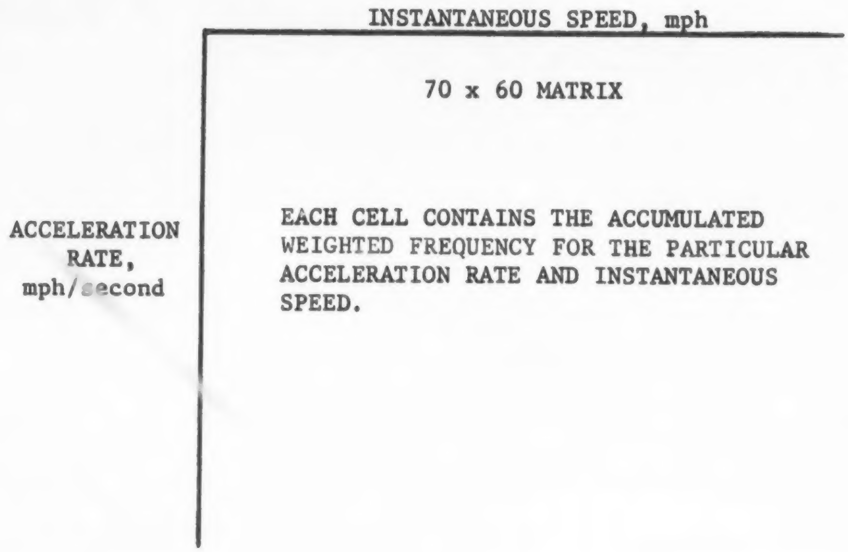

INSTANTANEOUS SPEED, mph
70 x 60 MATRIX
ACCELERATION RATE, mph/second
EACH CELL CONTAINS THE ACCUMULATED WEIGHTED FREQUENCY FOR THE PARTICULAR ACCELERATION RATE AND INSTANTANEOUS SPEED.

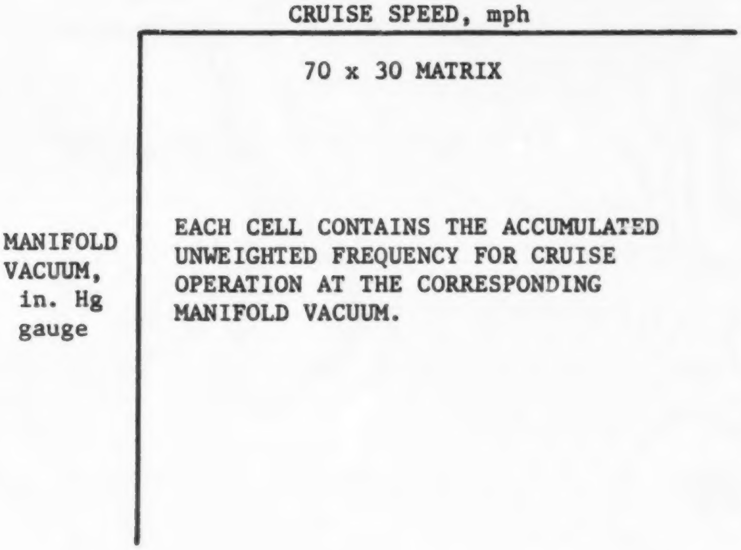
Figure 3-24 Acceleration-Rate-Versus-Instantaneous-Speed Matrix

acceleration and deceleration modes. The appropriate traffic density weighting factor is then accumulated in the matrix cell corresponding to the calculated acceleration rate. The instantaneous speed is the average of two consecutive speeds.

The acceleration-rate-versus-instantaneous-speed matrix does not provide any information about the shape of a specific acceleration or deceleration profile; the data are combined by instantaneous speed, independently of the initial and final speeds. Second-by-second speed data were therefore obtained on computer-punched cards to obtain data from which typical acceleration and deceleration profiles may be constructed. Various pairs of initial and final speeds were specified for which punched-card output was obtained.

Modes were selected on the basis of frequency of occurrence and to provide a representative sample of the 4900 modes in the mode matrix. One-half-mph tolerences are placed about the initial and final speeds and punched-card output is obtained for any selected mode whose initial and final speeds are within the speed bands specified. These punched cards may be used to create average characteristics for typical modes to provide insight into the variation of acceleration and deceleration profiles with geographical location.

The manifold-vacuum-versus-cruise-speed matrix, shown in Figure 3-25, is used to accumulate manifold-vacuum data for the various cruise modes. The manifold-vacuum scale extends from 0 to 30 inches of mercury gauge and is divided into 30 cells, each covering a range of one inch of mercury. A tally is accumulated in the appropriate cell for each second of observed cruise data. The data in this matrix are unweighted with respect to traffic


CRUISE SPEED, mph
70 x 30 MATRIX
MANIFOLD VACUUM, in. Hg gauge

EACH CELL CONTAINS THE ACCUMULATED UNWEIGHTED FREQUENCY FOR CRUISE OPERATION AT THE CORRESPONDING MANIFOLD VACUUM.

Figure 3-25 Manifold Vacuum Versus Cruise Speed

density because the recorded manifold-vacuum data are peculiar to the VOS vehicles. Only the cruise-mode data are represented in this matrix because of the relative stability of manifold vacuum for those modes.

The matrices described above provide a sound basis for characterizing vehicle operation. Since all matrices except the manifold-vacuum matrix have been weighted by the appropriate traffic density factors, these matrices provide an accurate representation of typical vehicle operation in the city for which the route was designed. Each of these matrices is calculated for every route replicate.

Since a complete set of matrices was determined for the data observed during each route replicate, a matrix merging technique was developed to combine any number of the same kind of matrix. In general, vehicle operation data were observed as each basic route was driven 14 times; i.e., replications were obtained twice per day for each of the five weekdays and twice per day for each of the two weekend days. The merging technique thus provides a complete set of matrices which represent vehicle operation over each route.

Merging of the mode matrices is limited to the total-time matrix and the mode-frequency matrix. The composite total-time matrix is obtained by adding the data from the corresponding cells for all route replicates being merged and dividing by the number of route replicates being merged. Let a_{1ij} be the entry for the mode having initial speed i and final speed j for the first route replicate total-time matrix. Similarly, let a_{2ij} through a_{nij} have the same meaning for route-replicate matrices 2 through n. The corresponding entry in the composite matrix, denoted by c_{ij}, is defined by

$$c_{ij} = \frac{1}{n} \sum_{k=1}^{n} a_{kij}.$$

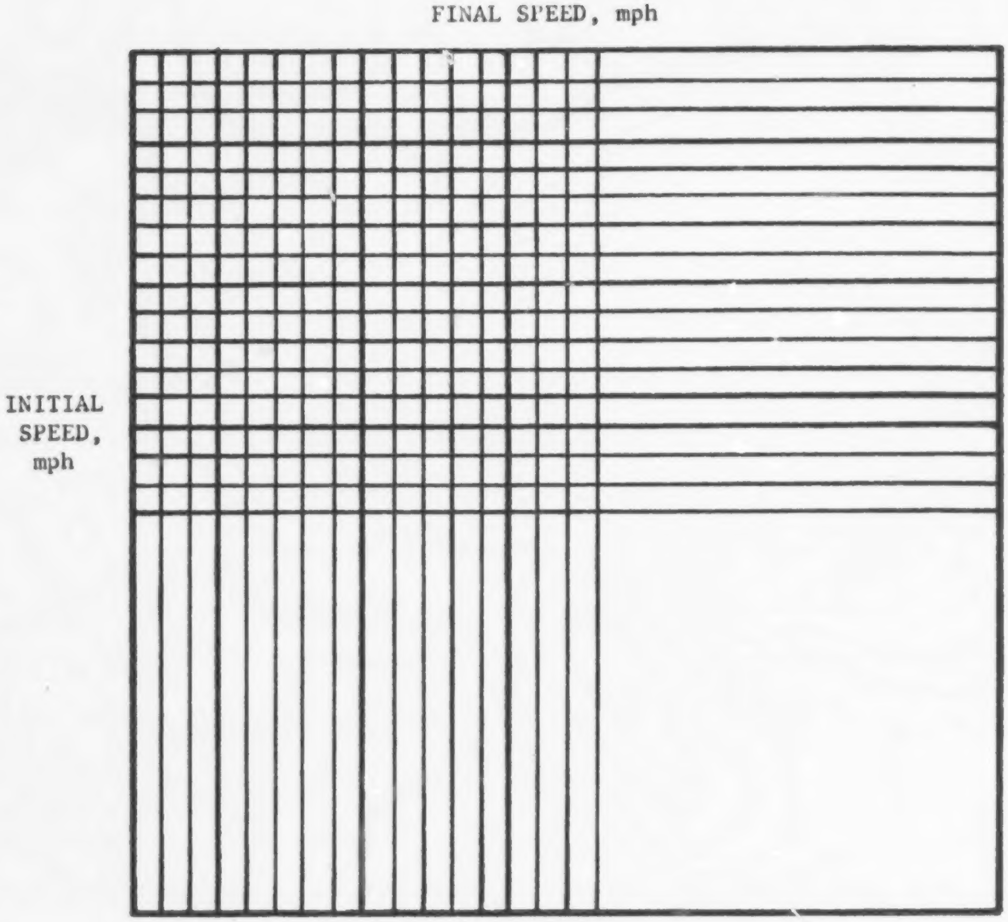
Performing this calculation over all i and j completes the composite total-time matrix. Division of each cell in the composite by the number of matrices being merged is required by computer storage limitations; the division keeps each cell entry relatively small. The composite mode-frequency matrix is obtained from the route-replicate mode-frequency matrices in the same manner as was the composite total-time matrix. The average-time-in-mode matrix and the transition-probability matrix are then calculated as previously described. These matrices are recalculated from the total-time and mode-frequency composites to eliminate inconsistencies in the composite mode matrices that will arise if the average-time-in-mode and the transition-probability composites are obtained directly by merging.

Composites for the auxiliary matrices are obtained by summing the data in corresponding cells for the same type of matrix for each route replicate being merged. This is performed in the same way as matrix merging for the total-time matrix. The only composite matrices whose elements are not divided by the number of matrices merged are the average-speed-versus-trip-length-and-time-of-day matrix and the manifold-vacuum-versus-cruise-speed matrix. The division is not necessary because these matrices contain actual unweighted frequencies that are relatively small, even after merging.

Higher levels of matrix merging may also be performed in the same fashion on several of the route composites to obtain a city composite. Lower-level composites, such as weekday and weekend composites, for the data obtained while observing vehicle operation over a specific route are also of some interest.

Creation of a sequence of vehicle operating modes from the speed/time data and subsequent storage and accumulation of these data into a set of mode and auxiliary matrices have provided a compact, easy-to-manipulate representation of driving patterns. However, it is clear that even though these matrices, containing as many as 4900 numbers, are easily handled on a computer, additional simplification is required for us to digest thoroughly what the data has to offer. The most straightforward approach to simplification is by matrix compacting. This procedure consists of restructuring the mode matrices to reduce the number of modes, while still retaining the basic characteristics inherent in the data represented by the 70 x 70 mode matrices. Because of built-in general features in the computer programs, the restructuring of the initial-speed and final-speed axes of the mode matrices may be accomplished in a variety of ways. The most practical form, based on matrix size and convenience of the resulting mode speeds, results when the initial-speed and final-speed axes are each partitioned into 14 intervals. These are defined as follows: one interval from 0 to 2.5 mph, 12 intervals of 5-mph width, and one interval which is 7.5 mph wide, thus providing an overall speed range from 0 to 70 mph.

Figure 3-26 shows the compact 14 x 14 mode matrix grid overlaid on the 70 x 70 mode matrix. As with matrix merging, only the total-time-in-mode matrix and the mode-frequency matrix are compacted; the


FINAL SPEED, mph
INITIAL SPEED, mph

NOTE: LIGHT LINES REPRESENT FINE MODE MATRIX GRID STRUCTURE (70 x 70).

HEAVY LINES REPRESENT COMPACTED MODE MATRIX GRID STRUCTURE (14 x 14).

Figure 3-26 Compact Matrix Grid Overlaid On 70 x 70 Mode Matrix Grid Structure

average-time-in-mode and transition-probability matrices are then recalculated. Each cell of the compact matrix is obtained by adding the data from all of the cells in the 70 x 70 matrix that lie within the cell from the compact matrix (Figure 3-26). With the exception of those cells which lie around the perimeter of the mode matrix, the data from 25 cells in the large mode matrix are contained in one cell of the compact matrix. It should be noted that all data are retained in this compacting procedure and that only the fineness of the details is modified. Patterns and characteristics representative of the data are more distinguishable in the compact matrices and the data are now in a manageable form for easy manipulation and for reporting.

3.5.1.2 Assessment and Modification of Preliminary Approach

Application of the data processing techniques described in Section 3.5.1.1 to VOS data collected in Los Angeles provided a basis for evaluation of the procedures. This checkout was essential, of course; further, the data processing computer program logic is of such a nature that a large amount of data is required to execute all of the options in the programs. Assessment of output based on a realistic sample of data afforded an opportunity to evaluate the results for inconsistencies and presented an opportunity to determine if the mode-matrix approach adequately provided an accurate description of vehicle operation. As a result of that analysis, various modifications and additions were made to the data processing techniques. This section contains a summary of the reasons for making modifications to the data processing techniques as well as a description of the modifications.

The large amount of computer output from processing VOS data required that the printed labels and general formatting be improved to make the matrices easier to identify and to make the output more readable. This reformatting was especially important with respect to the compacted mode matrices so that the hardcopy output from the computer could be easily reproduced for presentation in reports.

Analysis of a segment of recorded speed/time data revealed that the initial one or two seconds of acceleration or deceleration data were sometimes included with the previous cruise mode. This was eliminated by the revised mode logic shown in Figure 3-27. As an acceleration or deceleration mode is detected following a cruise mode, the logic regresses backwards in time to find the actual beginning of the data that satisfy the acceleration/deceleration criteria. Time is subtracted from the preceding cruise mode in the same amount as any time added to the acceleration or deceleration mode. The effect of this processing logic modification is shown in Figure 3-28, where the same speed/time data that were analyzed in Figure 3-18 are segmented into modes using the revised logic. The overall effect is to yield slightly shorter cruise modes and slightly longer acceleration and deceleration modes.

As noted above, the initial processing logic was such that multiple cruise modes could occur in sequence for speed data with small oscillations. This condition exists when a cruise mode is terminated by a speed outside the one-mph band, but is not sufficiently greater or less than the previous speed to satisfy the acceleration/deceleration criterion. These consecutive cruise modes, called step cruises, are actually part of a broader-band cruise that was segmented by the detail of the processing logic. This condition causes a serious problem when matrix compacting is attempted.

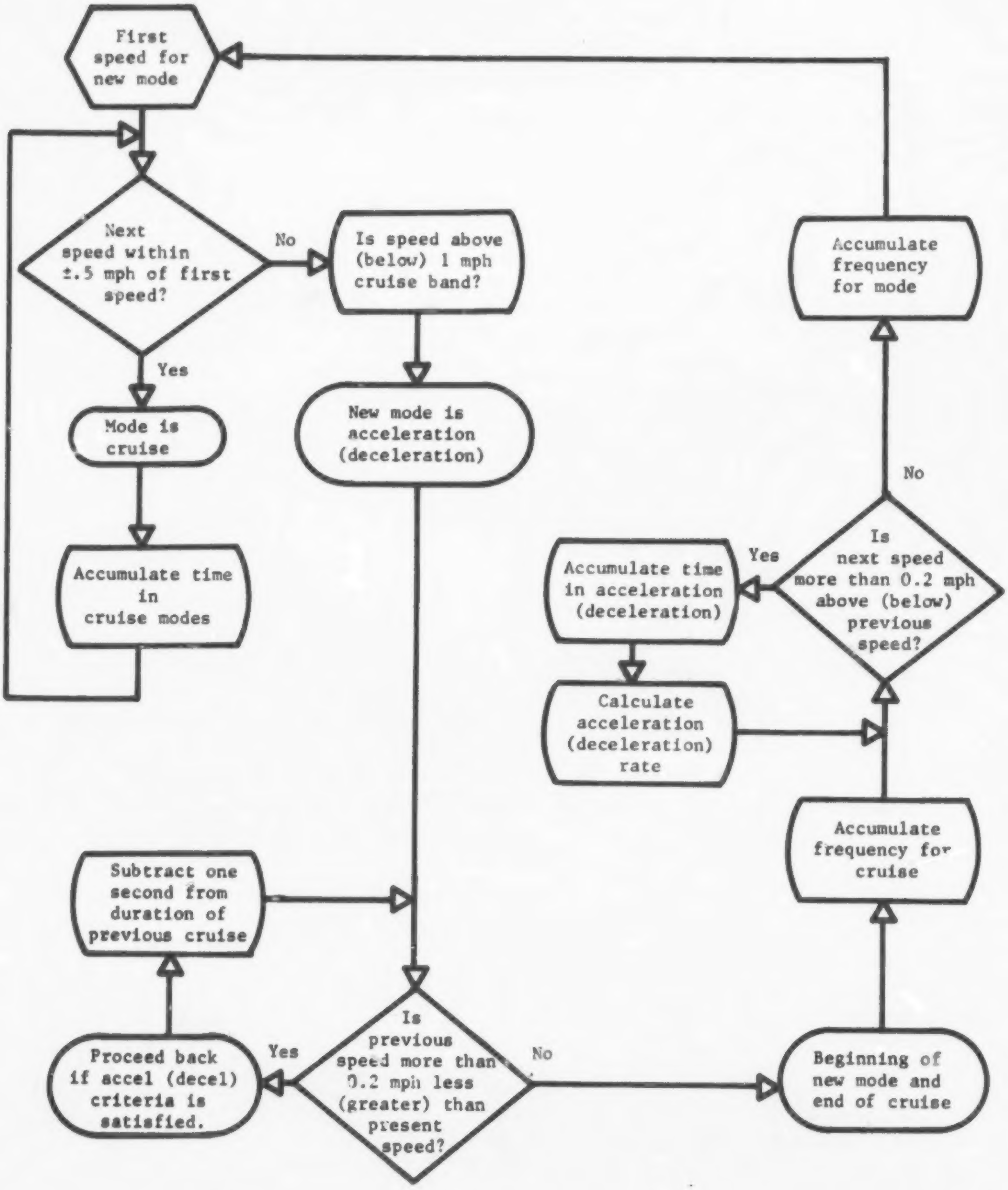
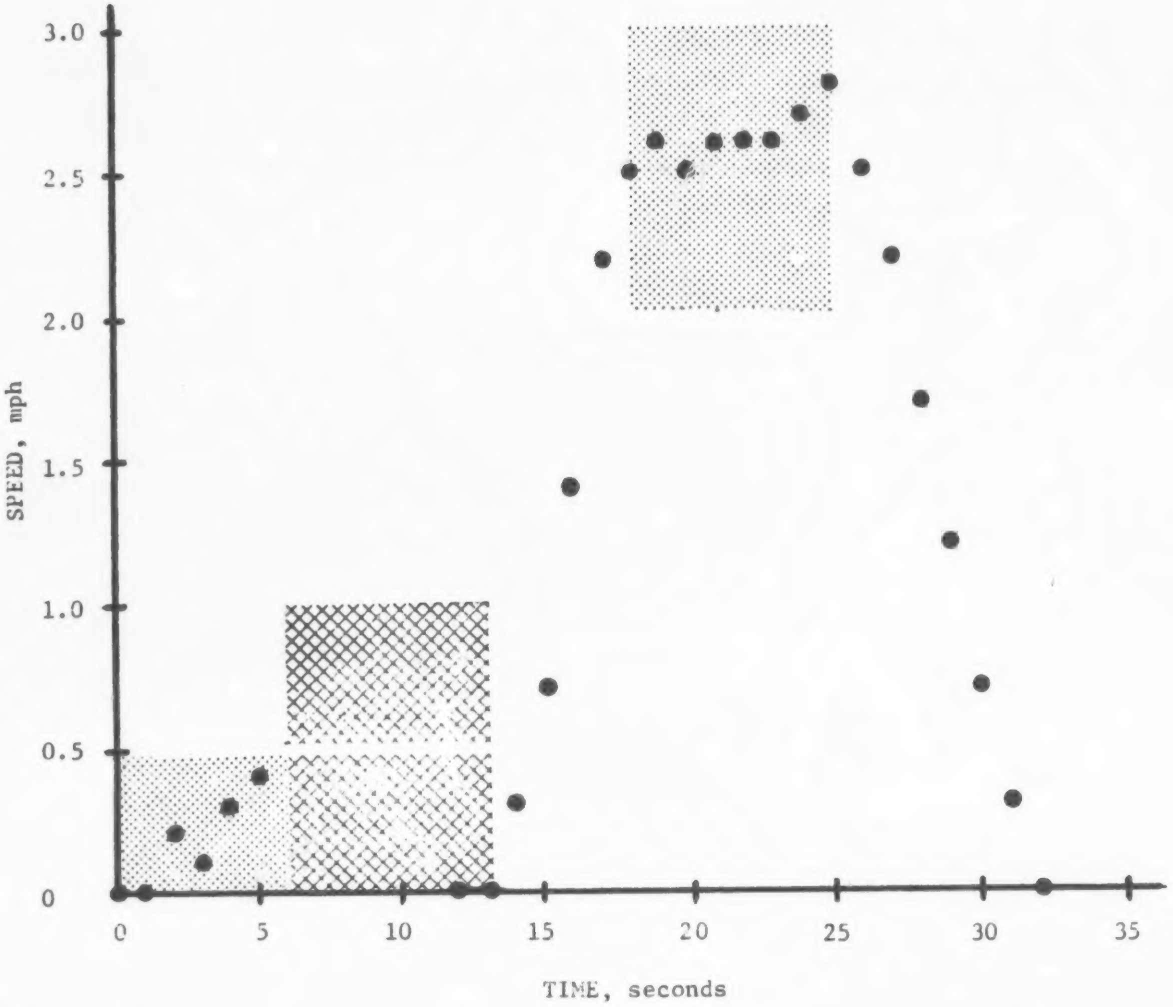

First speed for new mode
Next speed within ±.5 mph of first speed?
No
Yes
Is speed above (below) 1 mph cruise band?
Mode is cruise
Accumulate time in cruise modes
New mode is acceleration (deceleration)
Accumulate frequency for mode
No
Is next speed more than 0.2 mph above (below) previous speed?
Yes
Accumulate time in acceleration (deceleration)
Calculate acceleration (deceleration) rate
Accumulate frequency for cruise
Subtract one second from duration of previous cruise
Proceed back if accel (decel) criteria is satisfied.
Yes
Is previous speed more than 0.2 mph less (greater) than present speed?
No
Beginning of new mode and end of cruise

Figure 3-27 Modified Logic for Segmenting Speed/Time Data Into Modes



6 second cruise at 0.25 mph

7 second cruise at 0.25 mph

5 second accel from 0. mph to 2.5 mph

7 second cruise at 2.65 mph

7 second decel from 2.8 mph to 0. mph

NOTE: Shaded areas represent ± 0.5 mph cruise band about initial cruise speed.

Figure 3-28 Segmentation of Speed/Time Data Into Modes Using Modified Mode Logic

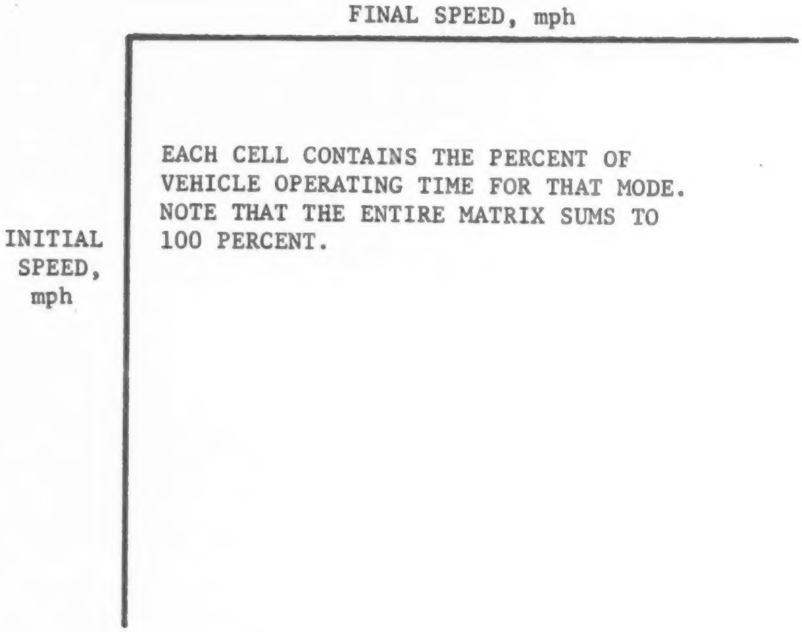
It is noted from Figure 3-26 that merging of the data to form the cruise modes in the compact matrices requires combining data that were classified as accelerations, cruises, and decelerations using the detailed 70 x 70 grid structure. All other modes being merged are distinctly accelerations or decelerations regardless of the grid structure that is selected for the compact matrices. The existence of step cruises and the process of combining all three types of modes into the cruise modes of the compact matrices resulted in excessively large cruise frequencies and, therefore, very small average times for the cruise modes. This problem was eliminated by imposing the reasonable logic that each acceleration or deceleration should be followed by one and only one cruise mode.

As a result, the total number of accelerations and decelerations in a given row must equal the total number of cruises for that row. After initial processing to yield the mode-frequency matrix, the mode frequency for each cruise is replaced by the sum of all non-diagonal frequencies in the row in which the cruise occurs. This program modification had its greatest impact on the preliminary results in that the average-time-in-mode matrix became realistic with respect to the cruise modes. It should be noted that the resulting mode-frequency matrix is composed of 50% cruises (including idles) and 50% accelerations and decelerations. The modified transition-probability matrix is thus calculated from the mode-frequency matrix as before, except that each row is normalized by dividing each non-diagonal entry by the sum of all non-diagonal frequencies. The transition probability is undefined for the cruise cells because a cruise does not constitute a transition.

Each set of mode matrices is created from a sample of vehicle operation data that is of variable size due to the fact that a different time is required to drive each route replicate. This causes difficulty in comparing the total-time-in-mode matrices and the mode-frequency matrices for different sets of data. This problem was easily resolved by creating the two normalized mode matrices shown in Figures 3-29 and 3-30. A normalized matrix is created simply by dividing each cell entry by the sum of all cells and expressing the result as a percentage. The entire matrix thus sums to 100 percent, since this represents all of the data. These two normalized matrices provide a consistent basis for comparing vehicle operation observed for any sets of data.

Following analysis of the data for a route replicate the normalized matrices are output on magnetic tape and on the printer together with the other mode matrices and auxiliary matrices. Four useful summary statistics are obtained for each of the normalized time-in-mode and normalized mode-frequency matrices. Summary percentages are calculated for idles, cruises, accelerations, and decelerations by accumulating the data from the cells for each mode type.

Matrix merging and compacting was an inefficient process using the initial techniques because computer core-storage limitations required relatively slow access to disk storage for each operation. Switching to a larger, more powerful computer allowed these operations to be performed in core with a great saving of computer time. This modification to the program did not affect the results, of course.


FINAL SPEED, mph
INITIAL SPEED, mph

EACH CELL CONTAINS THE PERCENT OF VEHICLE OPERATING TIME FOR THAT MODE. NOTE THAT THE ENTIRE MATRIX SUMS TO 100 PERCENT.

Figure 3-29 Normalized Time In Mode Matrix

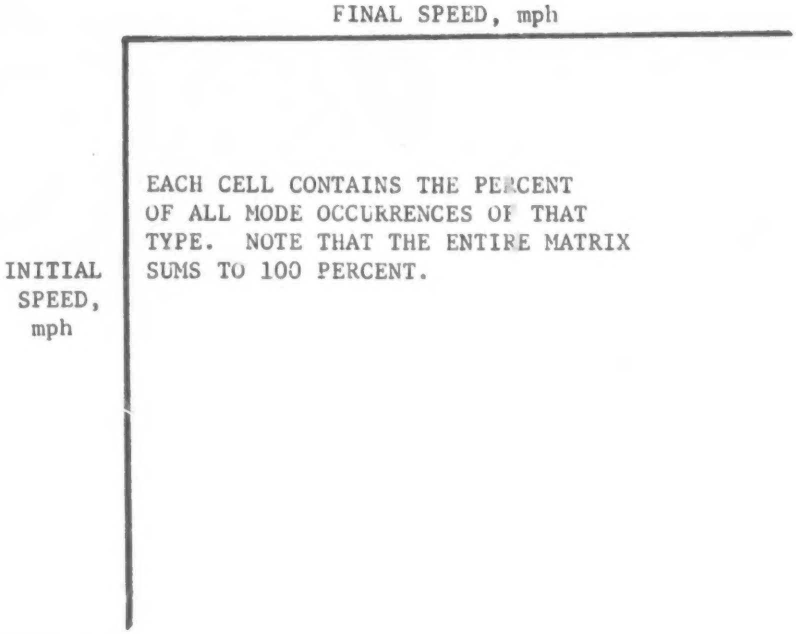
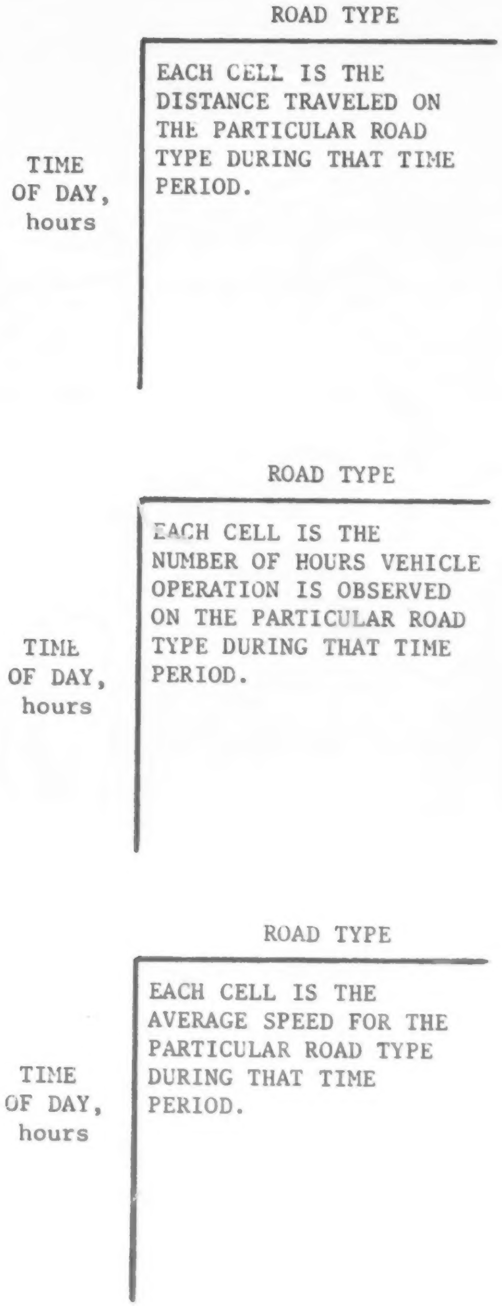

FINAL SPEED, mph
EACH CELL CONTAINS THE PERCENT OF ALL MODE OCCURRENCES OF THAT TYPE. NOTE THAT THE ENTIRE MATRIX SUMS TO 100 PERCENT.
INITIAL SPEED, mph

Figure 3-30 Normalized Mode Frequency Matrix

Average speed and mileage calculations during the preliminary data processing were made using the lower Darboux sum for accelerations and the upper Darboux sum for decelerations. Any inaccuracy resulting from this technique was eliminated by modifying the program to compute the Riemann sum. This more accurate computation of average speed and distance data was necessary because of another matrix that was developed to accommodate time and distance data. Figure 3-31 shows the 3-dimensional structure of the matrices in which were accumulated time, distance, and average speed versus road type and time of day. The time-of-day axis is partitioned into either 6 or 8 time slots, depending on whether the data are for weekends or weekdays, respectively. "Freeway" and "non-freeway" designate the two road type classifications for which data are obtained. The average-speed data from this matrix, in conjunction with the summary percentage statistics from the normalized time and normalized frequency matrices, present a concise description of typical vehicle operation in the city in which the data were obtained.

3.5.1.3 Computer Processing

The large volume of VOS data required that efficient computer processing be used to analyze the data. The requirement for good reliable data was ensured by the accurate, dependable DDAS and the use of high-quality magnetic tape. Transformation of the logic for developing the mode matrices into computer language was also important to ensure efficient and effective use of the capabilities of the computer. In addition, it was important to select a computer capable of performing all the intricate functions required to process the VOS data from magnetic tapes and to output the results on magnetic tape and on hardcopy.


ROAD TYPE
TIME OF DAY, hours

EACH CELL IS THE DISTANCE TRAVELED ON THE PARTICULAR ROAD TYPE DURING THAT TIME PERIOD.

ROAD TYPE
TIME OF DAY, hours

EACH CELL IS THE NUMBER OF HOURS VEHICLE OPERATION IS OBSERVED ON THE PARTICULAR ROAD TYPE DURING THAT TIME PERIOD.

ROAD TYPE
TIME OF DAY, hours

EACH CELL IS THE AVERAGE SPEED FOR THE PARTICULAR ROAD TYPE DURING THAT TIME PERIOD.

Figure 3-31 Time, Distance And Average Speed Versus Time Of Day And Road Type Matrices

The complete VOS data processing program, from initial raw data input to the final computer output, was modularized into logical units to guarantee easy computer program writing, debugging, and execution. Each computer program performs an integral task so that no overlapping occurs during processing. Partitioning the processing into separate tasks also provided a firm basis for evaluating the progress of the analysis as each task was performed. Since each task depends on successful completion of the preceeding task, it is important to have complete control of all stages of the data processing.

The following is a list of the computer programs that provide a complete analysis of VOS data:

- Data format conversion from 7 to 9 track
- Data processing (matrix development)
- Matrix merging and compacting
- Matrix printing
- Matrix comparison.

Flow diagrams showing the relationships between these computer programs are presented in Figures 3-32 and 3-33. All programs, except that providing raw data format conversion from seven to nine track, were written in Fortran language. Fortran is a high-level lenguage that provides efficient matrix operations as well as being versatile in all aspects of magnetic tape operations. The data conversion program was written in the relatively low level assembler language to make use of its capabilities for handling raw input data at low recording densities.

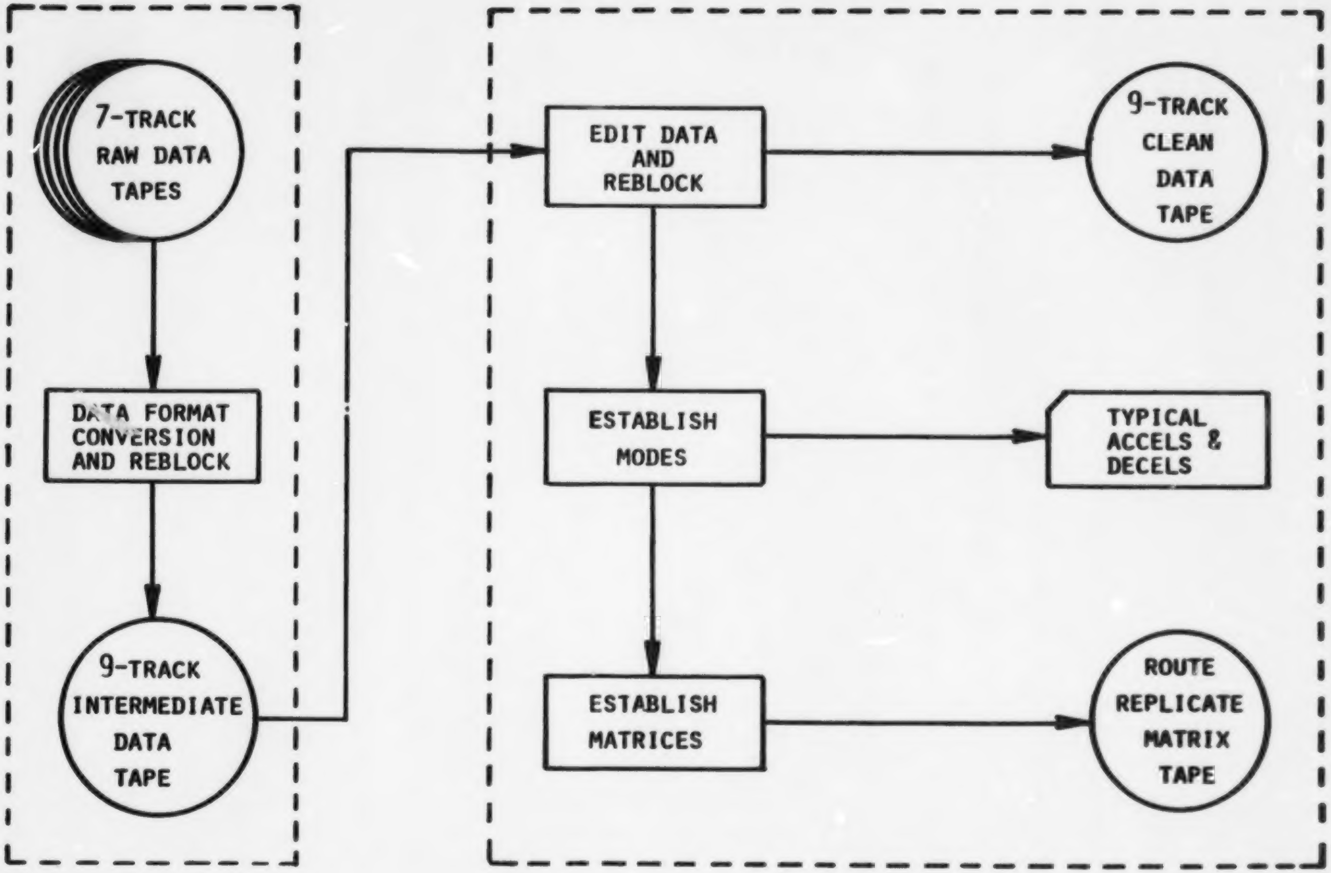

7-TRACK RAW DATA TAPES
DATA FORMAT CONVERSION AND REBLOCK
9-TRACK INTERMEDIATE DATA TAPE
EDIT DATA AND REBLOCK
9-TRACK CLEAN DATA TAPE
ESTABLISH MODES
TYPICAL ACCELS & DECELS
ESTABLISH MATRICES
ROUTE REPLICATE MATRIX TAPE

Figure 3-32 VOS Data Conversion and Data Processing Computer Programs

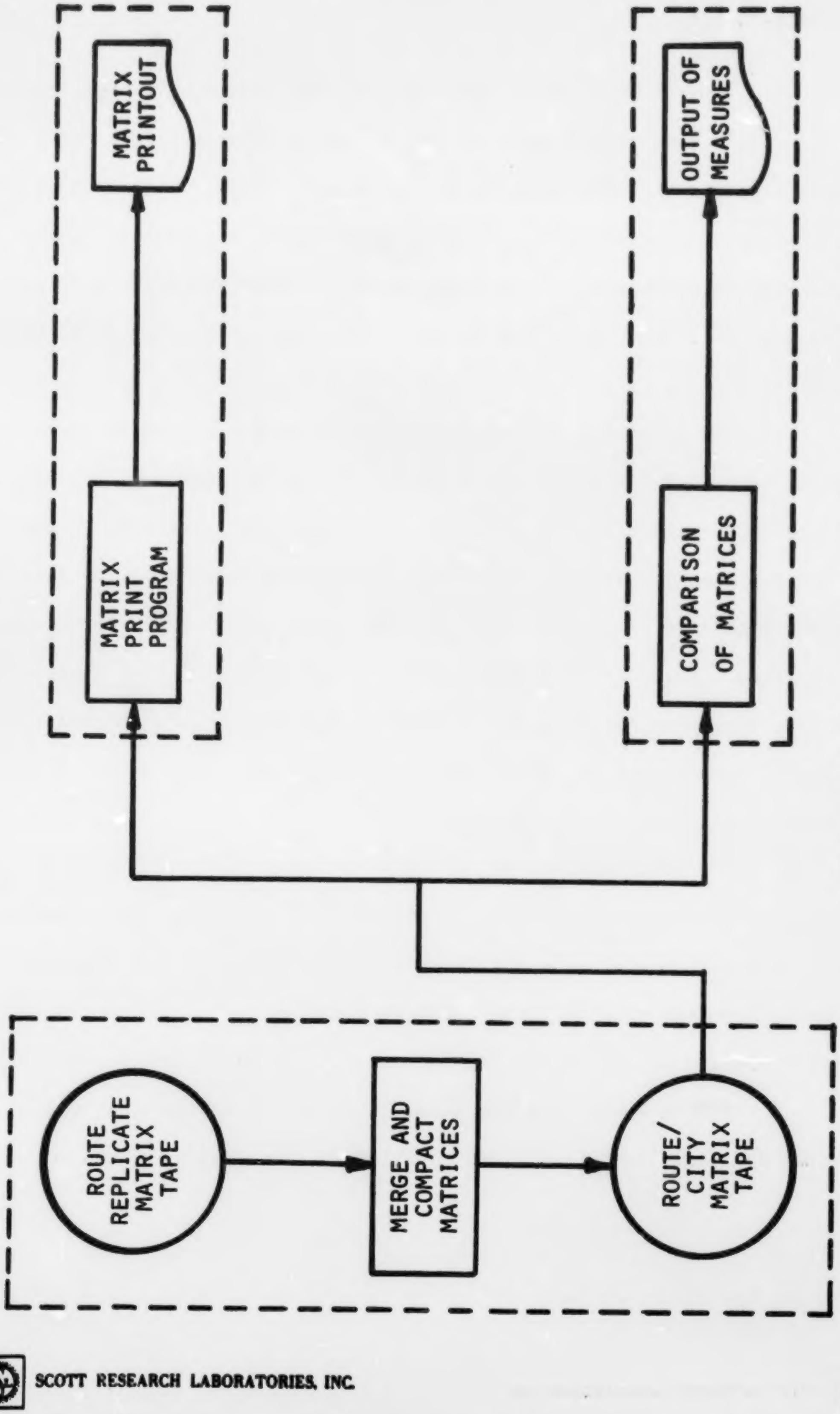

ROUTE REPLICATE MATRIX TAPE
MERGE AND COMPACT MATRICES
ROUTE/ CITY MATRIX TAPE
MATRIX PRINT PROGRAM
MATRIX PRINTOUT
COMPARISON OF MATRICES
OUTPUT OF MEASURES

Figure 3-33 VOS Auxiliary Data Processing Computer Programs

It will be recalled that the raw data recording format is seven track, with a recording density of 200 bpi using IBM-compatible code. The record size for the input data is 27 characters. These characteristics were chosen as most effective for data recording in the field. Highly sophisticated computers are not utilized to maximum capability when operating on data of this type, so a data format conversion program was written to transform the raw data input to a more useful format.

The converted data were recorded on magnetic tape at an 800-bpi density using a 9-track format. The record size was increased for greater efficiency by reblocking of the data, thus requiring fewer tape accesses during processing. The data conversion program also provided the first data editing functions. Data recorded with the wrong parity could not be read and so were eliminated. Illegal characters (a character other than a digit) that may appear on the data tape are identified by logic in the data processing program. These types of errors were rare; fewer than one recording error was observed per 1200-foot raw-data tape.

The major portion of the data reduction task is accomplished with the data processing computer program. The data for each route replicate are analyzed separately. The input data consist of those on the intermediate 800-bpi data tape obtained from the data conversion program and the SDC traffic density weighting factors for the city in which the data were obtained.

As the speed data are accumulated in the master mode matrix, another data editing is performed to eliminate non-digital characters and to smooth inconsistencies in the speed data. A speed inconsistency is defined to be a speed change of more than 10 mph per second. Linear interpolation is used to determine replacement speeds where these inconsistencies occur. A clean output data tape, using 9-track format at 1600 bpi, is prepared as the data are being analyzed. The auxiliary matrices are also accumulated during this part of the processing.

The punched-card output of typical acceleration and deceleration data is also prepared during data reduction. The mode matrices are then calculated from the master mode matrix upon completion of the processing of all data for a route replicate. All matrices, including the master mode matrix, are output on the route replicate matrix magnetic tape for storage and future data analysis. As each route replicate is processed, the clean data and the output matrices are accumulated on the respective output tapes. All output matrices are uniquely labeled for easy identification during analysis.

Following reduction of the data for all the route replicates for a route or a city, the appropriate matrices are merged and compacted to form the desired composites. Initially, the input data consist of the route replicate matrix tape; however, as higher-level composites are developed, any matrix tape may be used as input to this program. The output matrix tape consists of properly labeled route or city composites.

A different approach to merging was required to obtain the five-city composite matrices that represent vehicle operation in the urban areas where data were collected. The normal matrix merging approach was not appropriate because this would reflect a composite weighted by the data sample size for each city. The five-city composite was obtained from the city mode matrices by weighting each according to the number of vehicles registered in that urban area.

Hardcopy printer output may be obtained for any of the data matrices from the matrix printing program. Options are included to output selected sets of matrices in either 70 x 70 or compacted form. Therefore, any data matrix tape may be used as input to this program. This completes discussion of the package of computer programs used in the reduction and presentation of VOS data. The program for comparing and evaluating the output from two sets of input data will be discussed in Section 3.5.2.

Computer data processing and analysis were performed at the IBM Data center in Los Angeles. The computer was an IBM S/370 Model 155 with one megabyte of core storage. A schematic of the facilities is shown in Figure 3-34.

3.5.2 Data Analysis Procedures

The analytic methods may be viewed as fitting into either of two categories. The first includes what are called basic vehicle operation descriptors. The other category encompasses various techniques for comparing vehicle operation described by different sets of data. This section describes how these measures and techniques were developed and how the results may be used.

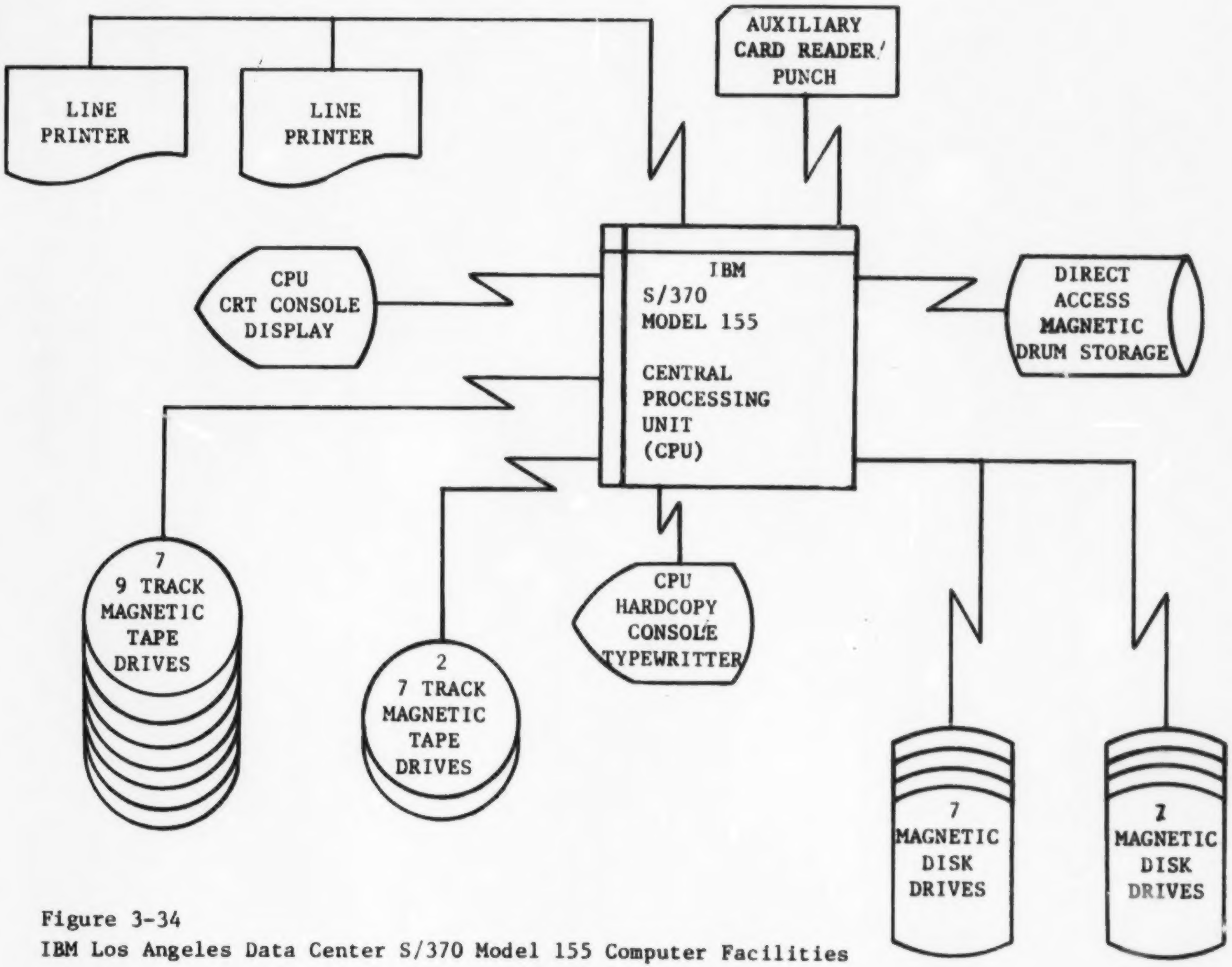

LINE PRINTER
LINE PRINTER
AUXILIARY CARD READER/ PUNCH
CPU CRT CONSOLE DISPLAY
IBM S/370 MODEL 155
CENTRAL PROCESSING UNIT (CPU)
DIRECT ACCESS MAGNETIC DRUM STORAGE
7 9 TRACK MAGNETIC TAPE DRIVES
2 7 TRACK MAGNETIC TAPE DRIVES
CPU HARDCOPY CONSOLE TYPEWRITTER
7 MAGNETIC DISK DRIVES
2 MAGNETIC DISK DRIVES

Figure 3-34
IBM Los Angeles Data Center S/370 Model 155 Computer Facilities

3.5.2.1 Basic Vehicle Operation Descriptors

One of the most useful descriptors of vehicle operation is average speed. The versatile nature of the data processing program provides a variety of average-speed statistics summarizing different aspects of the data. The most extensive average-speed data may be obtained from the matrix of average speed versus trip length and time of day (Figure 3-23). Data of a more practical nature are summarized in the matrices of time, distance, and average speed versus time of day and road type (Figure 3-31). These matrices also provide a speed averaged over all times of day for each road type for each route replicate. The average and standard deviation of the route replicate average speeds for an entire city provide a measure of the variation in vehicle operation due to daily traffic pattern fluctuations.

The time and frequency percentage statistics for vehicle operation during idles, cruises, accelerations, and decelerations provide insight into the driving habits of the individuals observed along each route. These percentage statistics are summarized for all route replicates in a city in the same way as for average speed.

The average-time-in-mode matrix is an excellent summary of how rapidly accelerations and decelerations are executed. The shapes of accelerations and decelerations may be obtained by averaging the profiles from the punch card output for each of them. Comparison of the average-time-in-mode profile for each city indicates the variation in driving habits between cities. The matrix of acceleration rate versus instantaneous speed provides information on acceleration and braking stresses to which typical vehicles are subjected under normal operation.

Average profiles of manifold vacuum versus cruise speed may be obtained to compare the operation of the VOS vehicles in each city surveyed. These data indicate vehicle operating fluctuations and the topographical nature of each city. The data may not be used to infer anything about typical vehicle operation in any of the cities, of course, because the observed manifold vacuum data are peculiar to the particular VOS vehicle from which they were obtained.

3.5.2.2 Comparisons of Vehicle Operation

The nine basic vehicle operation statistics, average speed and the eight mode percentages defined in the previous section, provide a useful basis for comparing driving habits from two geographical areas. A method was sought, however, which quantified the driving patterns for comparison. The search for general comparison techniques was centered around procedures that may be applied to the compacted normalized total-time and mode-frequency matrices. Priority was given to approaches that provided relatively few output measures. Applicability of the analysis to both the normalized total-time and normalized mode-frequency matrices was a requirement.

A method of summarizing differences between corresponding cells from two matrices being compared was the first technique developed. Summing differences between two sets of numbers that have the same sum will produce zero unless absolute values of the differences are used. If the differences are squared, however, division of these squared differencs by the corresponding cell entries from one of the matrices produces a measure of the relative difference between the matrices. Reference matrix cells having a value of zero can not be permitted, of course, so it was found to be advantageous to combine cells that may be expected to be zero or close to zero. This produced an added feature in that a measure was defined which was damped to small fluctuations in the two normalized matrices being compared. The matrix partition shown in Figure 3-35 was established so that computer processing could be used. The areas were selected on the basis of two criteria. The value for each of the 13 areas was constrained to be at least 5 percent, so that division by small numbers was eliminated. The areas also encompass modes of a similar nature. This analysis procedure produces a statistic, analogous to chi-square, that is called delta-square.

To illustrate the procedure, consider the calculation of delta-square for two normalized matrices. Let X_i and Y_i, $i=1,\ldots,13$, be the summed values for the thirteen areas shown in Figure 3-35 for each of two normalized matrices. If the reference matrix contains the Y_i, then delta-square is defined by:

$$\Delta^2 \sum_{i=1}^{13} \frac{(X_i - Y_i)^2}{Y_i}$$

It should be noted that two different values of delta-square will be obtained, depending on which matrix is selected as the reference. Two identical matrices will produce a delta-square of zero, while increasing values of delta-square indicate greater differences between the matrices. The delta-square statistic provides an overall measure of matrix similarity and may thus be viewed as a measure of the differences between two driving patterns.

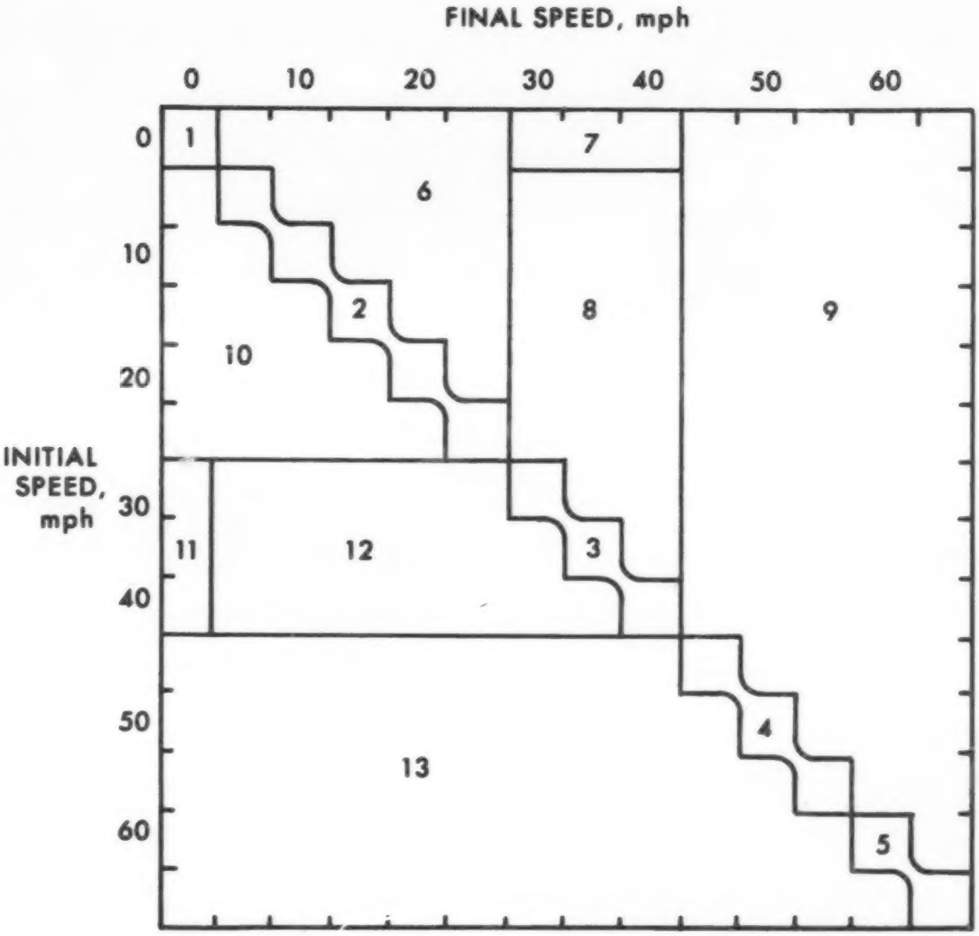

FINAL SPEED, mph
0
10
20
30
40
50
60
INITIAL SPEED, mph
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 3-35 Mode Matrix Partitioning For Delta-Square Analysis

Since the delta-square approach to evaluating matrix similarity requires the paritioning of each matrix into areas made up of one or more of the original driving modes, a comparison technique was sought which would be sensitive to variations in each of the 196 matrix modes. The procedure of linearly regressing the cells of one matrix on the cells of another matrix was determined to be an efficient method of making matrix comparisons. Correlation coefficients were computed for the cruise modes, acceleration modes, and deceleration modes (Figure 3-36), for two matrices and for the total matrices (mode-by-mode correlation of all 196 modes).

Each similarity comparison for 2 normalized matrices thus results in 8 linear regressions: four for the normalized time-in-mode matrix and four for the normalized mode-frequency-of-occurrence matrix. The regression analysis provides a correlation coefficient. the slope and intercept of the regression line, and the standard error of the estimate.

As will be seen in the results section, this linear regression technique yields great economy in the presentation of the data by representing the differences between two matrices by a single straight line. The correlation coefficients, of course, deviate from unity by an amount proportional to the differences between corresponding matrix cells. A computer program was written to perform the delta-square and linear regression analyses.

1 = CRUISE MODES (INCLUDING IDLE): 14 CELLS

2 = ACCELERATION MODES: 91 CELLS

3 = DECELERATION MODES: 91 CELLS

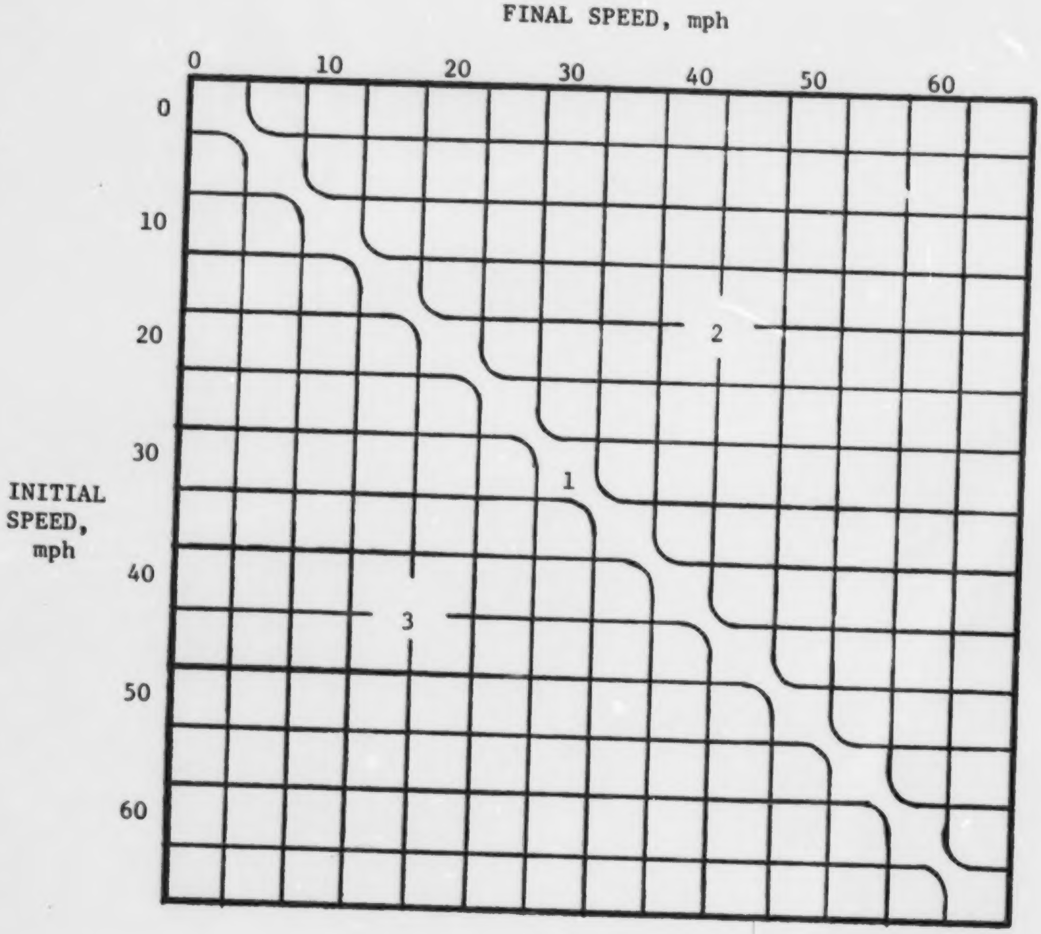

FINAL SPEED, mph
0
10
20
30
40
50
60
INITIAL SPEED, mph
0
10
20
30
40
50
60
1
2
3

Figure 3-36 Matrix Mode Categories For Linear Regression Analysis

4.0 RESULTS

This section discusses the processed data collected during the course of the program. The complete characterization of vehicle operating patterns is accomplished by reviewing 17 factors which contribute to a total assessment of the driving patterns for a route or group of routes. Basic descriptors of vehicle operation are average speed and mode composition; i.e., percent of total operating time and percent of mode frequency of occurrence at idle, cruise, acceleration, and deceleration.

Detailed information on vehicle modal operation is contained in the compacted speed-mode matrices. These matrices define the following operating characteristics as a function of initial speed versus final speed:

- Total time in mode
- Normalized time in mode
- Average time in mode
- Total mode frequency of occurrence
- Normalized mode frequency of occurrence
- Transition probability

4.1 DATA COMPARISONS

Two matrices, normalized time in mode and normalized mode frequency, are considered the primary descriptors of vehicle mode operating patterns. Comparisons between cities, or between a city and the five-city composite, are performed by using statistical techniques for determining the degree of similarity between the respective normalized time and frequency matrices. Appendix E contains detailed matrix information describing the vehicle operating patterns for each area surveyed during the program.

In addition to the aforementioned descriptors, information on acceleration/deceleration characteristics and intake manifold vacuum are presented to supplement the characterization of vehicle operating patterns.

4.1.1 Comparison of Basic Descriptors

Basic descriptors of operating patterns are compared and discussed in this section. These basic descriptors represent useful summaries of the detailed data over the total vehicle operating regime. The values for average speed and the mode composition statistics for the time and frequency matrices are reflections of the patterns contained in the detailed speed-mode matrices. The basic descriptors are essentially integrated forms of particular matrix information and simplify further analysis.

Table 4-1 presents the overall average speed results, with the freeway/non-freeway average speed values given for each survey. The grand average speed for the VOS program is a weighted average (weighted by vehicle registration) of the average speeds for the five cities surveyed and is shown in the second column of Table 4-1. This composite average speed was 26.0 mph. All further references to composite results will denote data weighted by vehicle registration.

The overall average speed from the individual urban area surveys ranged from 21.6 mph in New York City to 29.3 mph in Los Angeles, representing a variation of -16.9% to +12.7% from the composite value. The relatively high overall average speed in Los Angeles is believed to be a function of two primary factors. First, forty percent of the total miles surveyed in Los Angeles were on freeways. Additionally, non-freeway average speeds were higher because vehicles are permitted to make right

Table 4-1

Comparison of Basic Descriptors of Vehicle Operation

	5-City Comp.(1)	5-City Comp.(2)	N.Y.C.	Chicago	Cinci.	Houston	L.A.	L.A.-4(3)	L.A.-4(4)
Total Miles	-	-	3763.8	4381.0	2008.5	4466.3	7845.5	644.0	454.3
Total Freeway Miles	-	-	1183.8	1046.6	460.1	1390.4	3141.6	157.7	111.9
% Freeway Miles	29.9	32.7	31.4	23.9	22.0	32.2	40.0	24.5	24.6
Average Speed: Freeway, mph	48.1	46.5	40.5	46.5	54.6	50.3	48.7	45.2	28.3
Average Speed: Non-Freeway, mph	21.6	21.3	17.8	21.3	22.4	23.0	23.2	17.8	15.5
Average Speed: Overall, mph	25.8	26.0	21.6	24.5	25.9	27.7	29.3	21.0	17.4

(1) Cities weighted equally
(2) Cities weighted by vehicle registration
(3) Results are for defined hours 9:00 a.m. - 11:00 a.m. and 1:00 p.m. - 3:00 p.m.
(4) Results are for off hours 7:00 a.m. - 9:00 a.m. and 3:00 p.m. - 5:00 p.m.

hand turns "on the red" at most traffic light intersections in Los Angeles, thereby decreasing idle time. The slow overall average speeds witnessed in the New York City area are believed to be caused by extreme traffic density, and to a lesser degree, street maintenance deficiencies.

Average speeds on freeway segments ranged from 40.5 mph in New York City to 54.6 mph in Cincinnati, with a composite value of 46.5 mph. The freeway system in urban Cincinnati is limited, in extent, and the high average speed obtained indicates minimal traffic congestion. Non-freeway average speeds ranged from 17.8 mph in New York City to 23.2 mph in Los Angeles. The composite non-freeway average speed was 21.3 mph.

Vehicle operating data showing the average speed values obtained over the LA-4 road route are also included in Table 4-1. All three average speed measurements for the LA-4 defined hours were lower than the corresponding urban Los Angeles values. The location of the LA-4 route (in central L.A. where traffic density is relatively high), the numerous traffic lights, and the lower percentage of freeway miles over the LA-4 road route all contributed to the lower average speed values. Off-hours LA-4 speed values, in comparison to the LA-4 defined-hours data, were slower yet. A marked reduction in average speed on freeways segments and minor decreases on non-freeway segments were observed to result from increased traffic density during the busier hours (off hours).

4.1.2 Mode Composition

4.1.2.1 Distribution of Total Time by Mode

The distribution of total vehicle operating time in the various modes is reflected in the speed-mode matrices. By adding the times accumulated in the 13 cruise cells of a 14 x 14 normalized time matrix, a value for the percent of total time spent at cruise conditions is obtained. Similarly, data contained in the 91 cells representing various acceleration modes and in the 91 cells for deceleration modes were summed to yield the percent of time spent in each of those two general mode cateogries. The remaining cell of the matrix represents the percent of time spent at idle.

The above summation procedure was performed on the normalized time-in-mode matrices for each city, for the five-city composite, and for the LA-4 route. Table 4-2 presents the results of this summary evaluation. The five-city composite value for percent of total time at idle conditions is 13.06%. Percent of total time at idle ranged from 10.13% in Los Angeles to 17.45% in New York City. The relatively low value observed in L. A. is probably related to the traffic regulations which allow right hand turns "on the red" at most traffic lights. The value for percent idle time witnessed in New York City was markedly greater than that observed in the other four urban areas, and is attributed primarily to greater traffic congestion.

Vehicle operation during the defined hours on the LA-4 route resulted in a percent idle time nearly 3½ percent greater than the corresponding value for urban Los Angeles. During the off hours, the percent time at idle for the LA-4 off-hours compares closely with that for New York City. In both cases the major influencing factors are considered to be high traffic density and frequency of traffic lights.

In general, the values for percent of total time spent at cruise conditions appears to vary inversely with percent idle time in the five

Table 4-2

Distribution of Total Time in Mode Categories

	5-City Comp.(1)	5-City Comp.(2)	N.Y.C.	Chicago	Cinci.	Houston	L.A.	L.A.-4(3)	L.A.-4(4)
% Total Time, Idle	12.87	13.06	17.45	14.11	11.34	11.30	10.13	13.56	18.43
% Total Time, Cruise	31.83	31.50	26.49	30.86	30.72	36.80	34.28	27.25	25.42
% Total Time, Acceleration	29.08	29.16	29.12	28.30	30.89	27.35	29.78	31.73	29.82
% Total Time, Deceleration	26.23	26.30	26.95	26.78	27.06	24.58	25.82	27.49	26.28

(1) Cities weighted equally
(2) Cities weighted by vehicle registration
(3) Results are for defined hours 9:00 a.m. - 11:00 a.m. and 1:00 p.m. - 3:00 p.m.
(4) Results are for off hours 7:00 a.m. - 9:00 a.m. and 3:00 p.m. - 5:00 p.m.

cities. New York City, which had the highest idle value, yielded the lowest percentage of time at cruise. Houston, which had the second lowest percent of time at idle, had the highest percent of time at cruise conditions. The sum of percent time at idle plus percent time at cruise varied throughout a range from 42.06% (Cincinnati) to 48.10% (Houston). A similar trend was observed for LA-4 results during both time periods. However, the sums for percent idle time plus percent cruise time were somewhat lower at 39.81% and 43.85% for the defined hours and the off hours, respectively.

The percent of total time spent accelerating and decelerating did not vary greatly between the five cities. The composite value for percent time accelerating was 29.16%, with a total range of only 3.54%. For percent time decelerating, the composite value equalled 26.30%, with a total range of only 2.48%. The percent of total time spent accelerating and decelerating on the LA-4 route did not indicate any unusual trends.

4.1.2.2 Distribution of Mode Frequency by Mode Categories

Detailed mode frequency of occurrence data are contained in the 14 x 14 speed-mode matrices. To derive basic summary information, individual cell contents were combined to generate percent of mode frequency in the four general categories of idle, cruise, acceleration, and deceleration. The summations were performed on the data contained in the normalized mode frequency of occurrence matrices, as described above. The results of this evaluation are shown in Table 4-3.

The summary results from this evaluation are essentially controlled by the mode-sequence logic. This sequence logic, as discussed in Section 3.5, constrains the frequency data such that the sum of the

Table 4-3

Distribution of Mode Frequency in Mode Categories

	5-City Comp.(1)	5-City Comp.(2)	N.Y.C.	Chicago	Cinci.	Houston	L.A.	L.A.-4(3)	L.A.-4(4)
% Frequency, Idle	7.48	7.59	7.60	7.81	7.42	6.97	7.60	9.50	10.70
% Frequency, Cruise	42.52	42.41	42.40	42.19	42.58	43.03	42.40	40.50	39.30
% Frequency, Acceleration	25.34	25.26	25.43	25.38	25.44	25.43	25.04	25.26	25.41
% Frequency, Deceleration	24.66	24.74	24.57	24.62	24.57	24.57	24.96	24.74	24.59

(1) Cities weighted equally
(2) Cities weighted by vehicle registration
(3) Results are for defined hours 9:00 a.m. - 11:00 a.m. and 1:00 p.m. - 3:00 p.m.
(4) Results are for off hours 7:00 a.m. - 9:00 a.m. and 3:00 p.m. - 5:00 p.m.

acceleration and deceleration mode frequencies equals the sum of the idle and cruise mode frequencies.

The five-city composite values for mode frequency of occurrence are:

- Idle = 7.59%
- Cruise = 42.41%
- Acceleration = 25.26%
- Deceleration = 24.74%

As evidenced by the individual values shown in Table 4-3 for each of the five cities, there is very little between-city variation in any of the four categories.

A greater frequency of idle modes was observed on the LA-4 route than for any of the five urban areas. During the off-hours on the LA-4 route, the percent frequency of idle modes was over 3% greater than the composite (due to the previously-mentioned influencing factors).

4.1.3 Correlation of Matrix Information

The discussions of the average-speed data and the mode-composition statistics provides basic insight into the nature of the results obtained in each urban area. Another approach to the comparison and evaluation of vehicle operating patterns is provided by the correlation technique discussed in Section 3-5.

4.1.3.1 Correlation of Normalized Time Matrices

Normalized time in mode matrices for each survey area and for the five-city composite were cross-correlated to evaluate similarities between survey areas. Values for the correlation coefficients, r, derived from linear regression analysis, are presented in Table 4-4. Each

TABLE 4-4

CORRELATION COEFFICENTS
NORMALIZED TIME IN MODE COMPARISON

LEGEND

CRUISE MODES
ACCEL MODES
DECEL MODES
OVERALL MATRIX

	LA	HOUSTON	CINCI	CHICAGO	NYC
5-CITY COMP	.94 .96 .97 .96	.92 .98 .98 .96	.98 .98 .98 .98	.99 .98 .99 .99	.96 .94 .96 .96
LA		.90 .96 .95 .95	.94 .96 .94 .96	.88 .92 .88 .92	.83 .87 .80 .86
HOUSTON			.95 .98 .98 .97	.89 .95 .95 .94	.82 .91 .90 .88
CINCI				.96 .97 .95 .97	.90 .94 .92 .93
CHICAGO					.97 .98 .97 .98

	LA-4 DEFINED HOURS
LA-4 OFF HOURS	.97 .97 .97 .97
LA	.78 .80 .78 .84

of the five cities is compared with the composite and with each other city. Normalized time values for the cruise modes (including the idle modes), acceleration modes, and deceleration modes were correlated as well as the overall matrices.

Each of the five urban areas is similar to the five-city composite, as evaluated with the overall matrix correlation coefficients which range from 0.959 to 0.989. In the comparison of matrix data between individual cities, values of r between the overall matrices ranged from 0.860, for LA versus New York City, to 0.976, for Chicago versus New York City.

Using this technique to compare the data contained in the normalized time matrices for LA-4 defined hours versus urban LA, an r value of 0.843 resulted. This indicates that these two sets of data were the least similar of all the pairs evaluated. LA-4 off-hours data had a 0.973 correlation coefficient with LA-4 defined-hours data for normalized time.

4.1.3.2 Correlation of Normalized Mode Frequency Matrices

Correlations were also used to compare the normalized mode-frequency-of-occurrence matrix data for each of the five cities with the composite and with each other. Normalized mode-frequency data, being a more stable measure of driving patterns because they are constrained by the mode-sequence logic, yielded higher r values in all cases than did the respective normalized time in mode data. The results are shown in Table 4-5.

The correlation coefficients for each city versus the composite are plotted in Figure 4-1. In this illustration, bracketed cities have

TABLE 4-5

CORRELATION COEFFICIENTS

NORMALIZED MODE FREQUENCY OF OCCURRENCE COMPARISON

LEGEND

CRUISE MODES
ACCEL MODES
DECEL MODES
OVERALL MATRIX

	LA	HOUSTON	CINCI	CHICAGO	NYC
5-CITY COMP	.97 .97 .97 .99	.97 .97 .96 .98	.97 .97 .97 .98	.98 .98 .98 .99	.97 .96 .96 .98
LA		.97 .96 .95 .98	.98 .96 .95 .98	.91 .91 .90 .96	.89 .89 .88 .95
HOUSTON			.99 .98 .98 .99	.93 .92 .93 .97	.88 .88 .90 .95
CINCI				.92 .93 .93 .96	.89 .89 .90 .95
CHICAGO					.98 .97 .97 .99

	LA-4 DEFINED HOURS
LA-4 OFF HOURS	.98 .96 .96 .99
LA	.82 .81 .79 .90

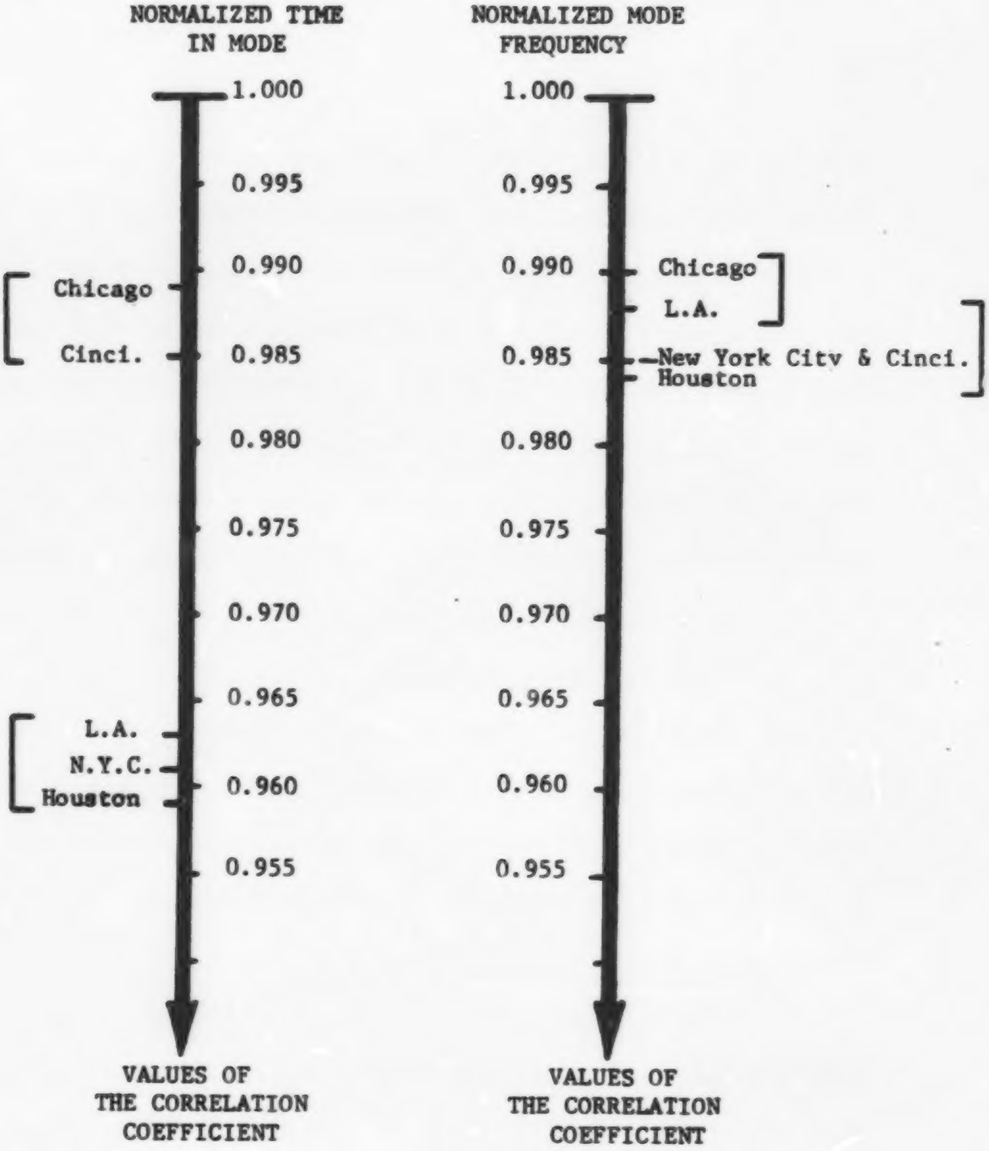


Figure 4-1 Relative Correlation of Each City versus the Composite

correlations with the composite which are not significantly different at the 95% confidence level. For example, Cincinnati had a correlation coefficient for the normalized time matrix equal to 0.985. An interval about this value from 0.980 to 0.989 represents the range of r values that would be obtained 95% of the time if Cincinnaiti were surveyed a large number of times. Since the correlation coefficient for Chicago versus the composite equals 0.989, and this value is contained within the 95% interval about Cincinnati, the Chicago and Cincinnati correlations with the composite are not significantly different.

4.1.4 Delta-Square Evaluation

In addition to the correlation studies, delta-square (modified chi-square) evaluations were performed on the same matrix data, as discussed in Section 3.5. Delta-square values can range from 0.0, representing identical matrices, to very large numbers when the matrices are very different.

The delta-square evaluation was performed on the normalized time-in-mode matrices and the normalized mode-frequency matrices for each city versus the five-city composite and for each city versus each other city. The results are given in Tables 4-6 and 4-7.

4.1.5 Supplemental Information

Up to this point in the discussion of the results, vehicle operating patterns have been described using the information contained in the speed-mode matrices. Additional information was generated to aid in the understanding of acceleration/deceleration characteristics and intake manifold vacuum curves.

Table 4-6

Delta-Square Values For Each City versus the 5-City Composite

	Delta-Square Value	
City	Normalized Time in Mode	Normalized Mode Frequency
L.A.	5.8	2.5
Houston	4.8	1.9
Cinci.	1.6	1.8
Chicago	1.9	1.5
N.Y.C.	8.6	3.6

TABLE 4-7

OVERALL MATRIX SIMILARITY
Δ - SQUARE VALUES

LEGEND

NORMALIZED TIME COMPARISON
NORMALIZED MODE FREQUENCY COMPARISON

	LA	HOUSTON	CINCI	CHICAGO	NYC
5-CITY COMP	5.8 2.5	4.8 1.9	1.6 1.8	1.9 1.5	8.6 3.6
LA		7.6 1.1	6.3 2.2	18.2 9.8	55.9 14.2
HOUSTON			3.8 0.4	7.9 6.3	23.9 10.6
CINCI				5.3 6.1	17.4 9.3
CHICAGO					5.5 1.4

	LA-4 DEFINED HOURS
LA-4 OFF HOURS	6.2 3.5
LA	31.5 20.0

4.1.5.1 Acceleration/Deceleration Characteristics

Matrices were generated for each city and the five-city composite to characterize acceleration and deceleration rates at instantaneous speeds. Figure 4-2 presents a graph of acceleration and deceleration rates versus instantaneous speed for the five-city composite data. The average acceleration rate curve reaches a maximum value of approximately 2.45 mph/second and the average deceleration curve peaks at approximately 2.25 mph/second. However, the curves defining the average-plus-two-standard-deviations values of acceleration and deceleration indicate that the decelerations are distributed over a greater range.

The frequencies of accelerations and decelerations at the higher rates is shown more precisely by the distribution functions in Figure 4-3 which give the percent of accelerations whose rates exceed any given rate. Figure 4-4 presents the analogous distribution functions for decelerations.

Acceleration and deceleration characteristics varied very little between the five cities. Data were processed to allow drawing profiles of typical acceleration and deceleration curves (speed versus time). Figure 4-5 presents typical 0-30 mph acceleration curves for the individual cities. Typical 30-0 mph deceleration profiles for the five cities are shown in Figure 4-6.

Of particular interest is the fact that Los Angeles, which had the highest average speed, indicates the slowest typical acceleration profile for the 0-30 mph case. Conversely, New York City had the lowest overall average speed and the highest rate of acceleration profile for typical 0-30 mph accelerations.

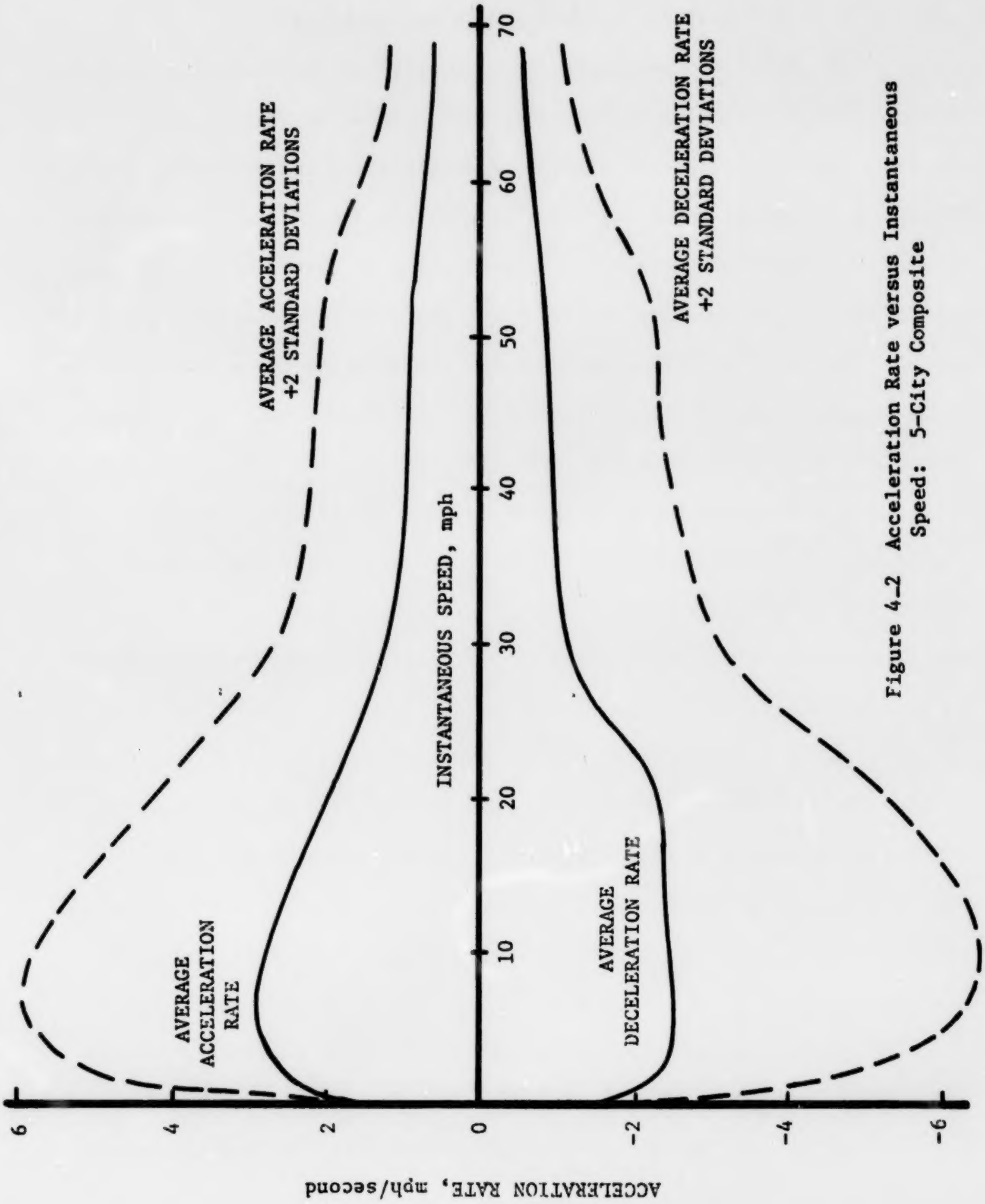
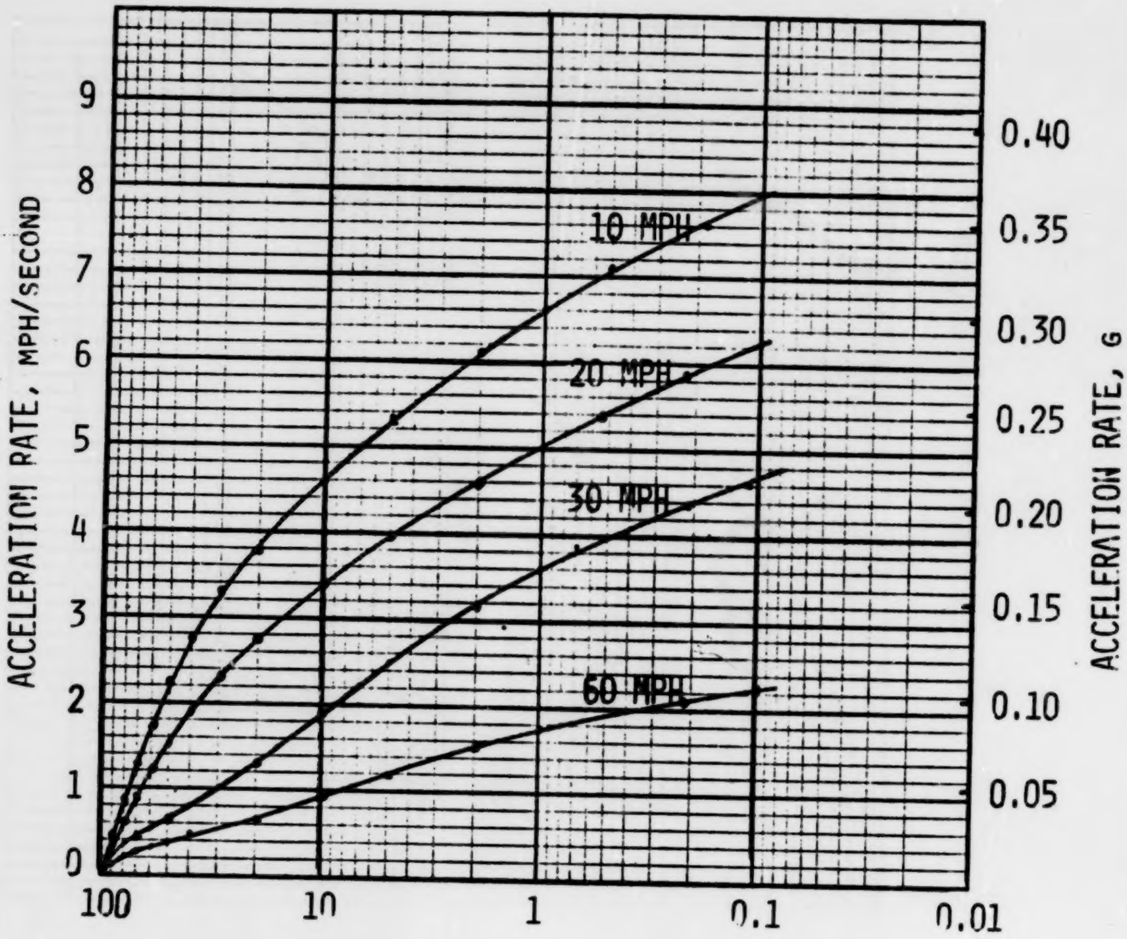


Figure 4-2 Acceleration Rate versus Instantaneous Speed: 5-City Composite



PERCENT OF ACCELERATIONS AT
A FASTER RATE THAN SHOWN

FIGURE 4-3 DISTRIBUTION FUNCTIONS OF 5-CITY-COMPOSITE ACCELERATIONS AT VARIOUS INSTANTANEOUS SPEEDS

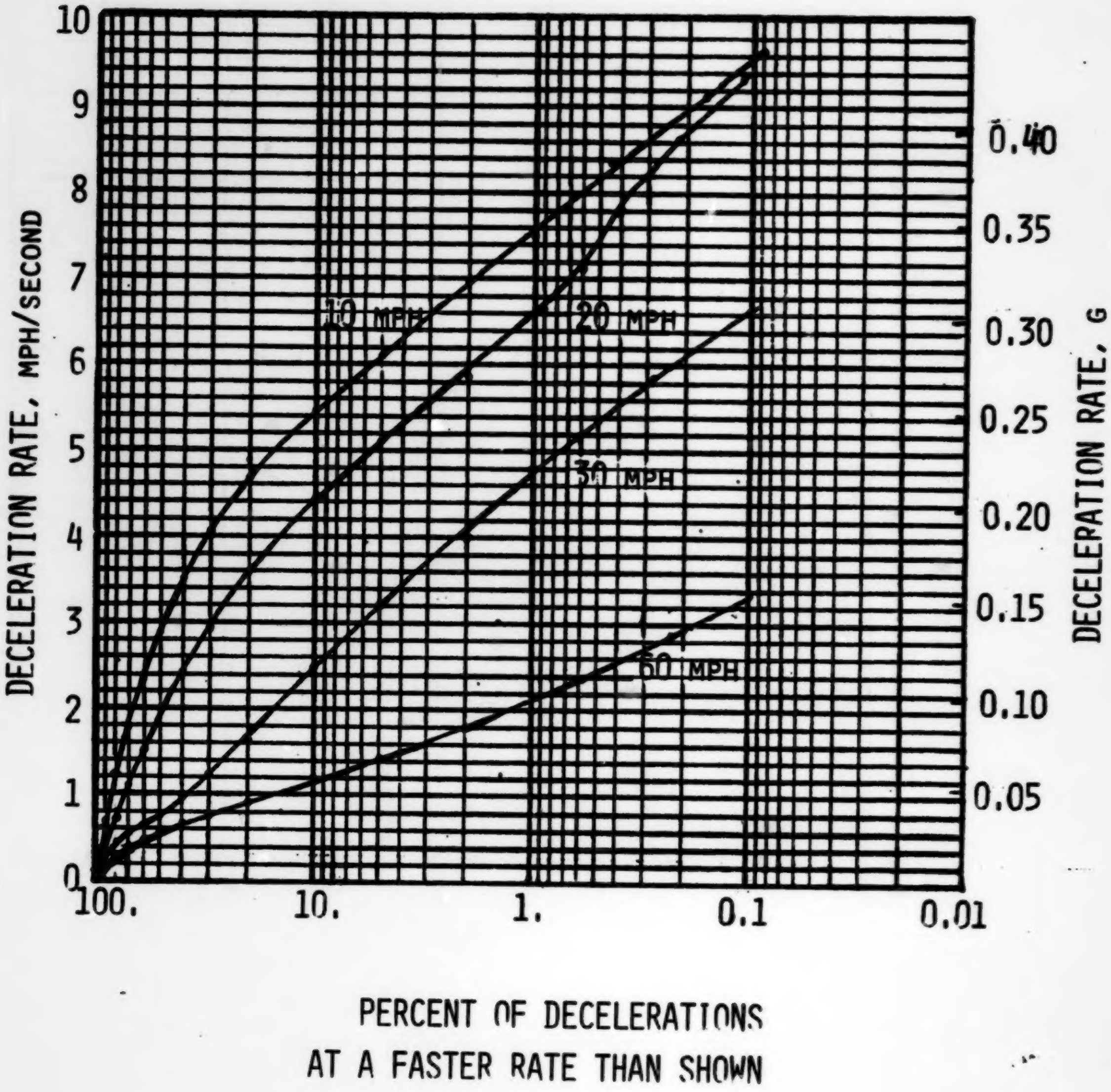


FIGURE 4-4 DISTRIBUTION FUNCTIONS OF 5-CITY COMPOSITE DECELERATIONS AT VARIOUS INSTANTANEOUS SPEEDS

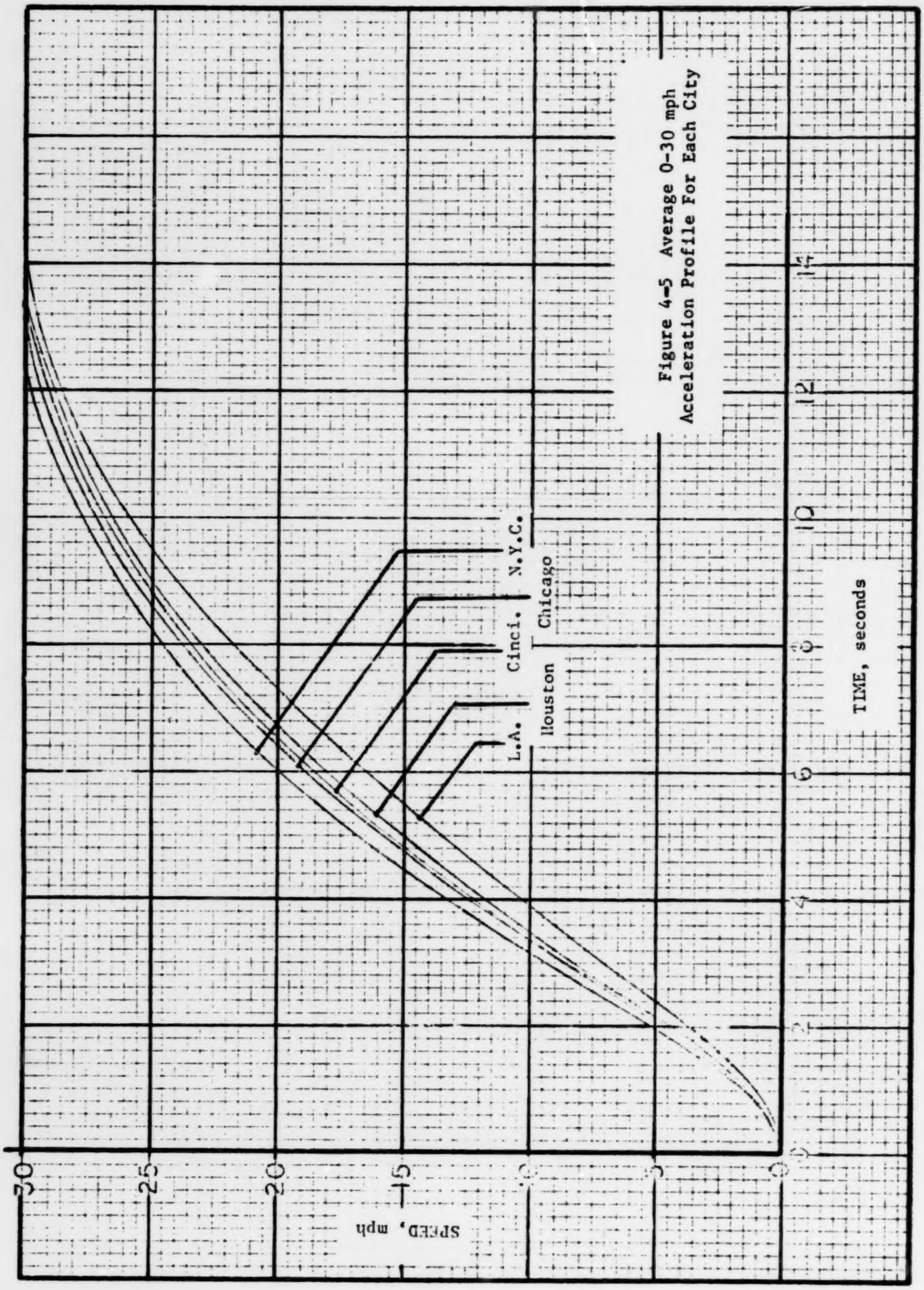


Figure 4-5 Average 0-30 mph Acceleration Profile For Each City

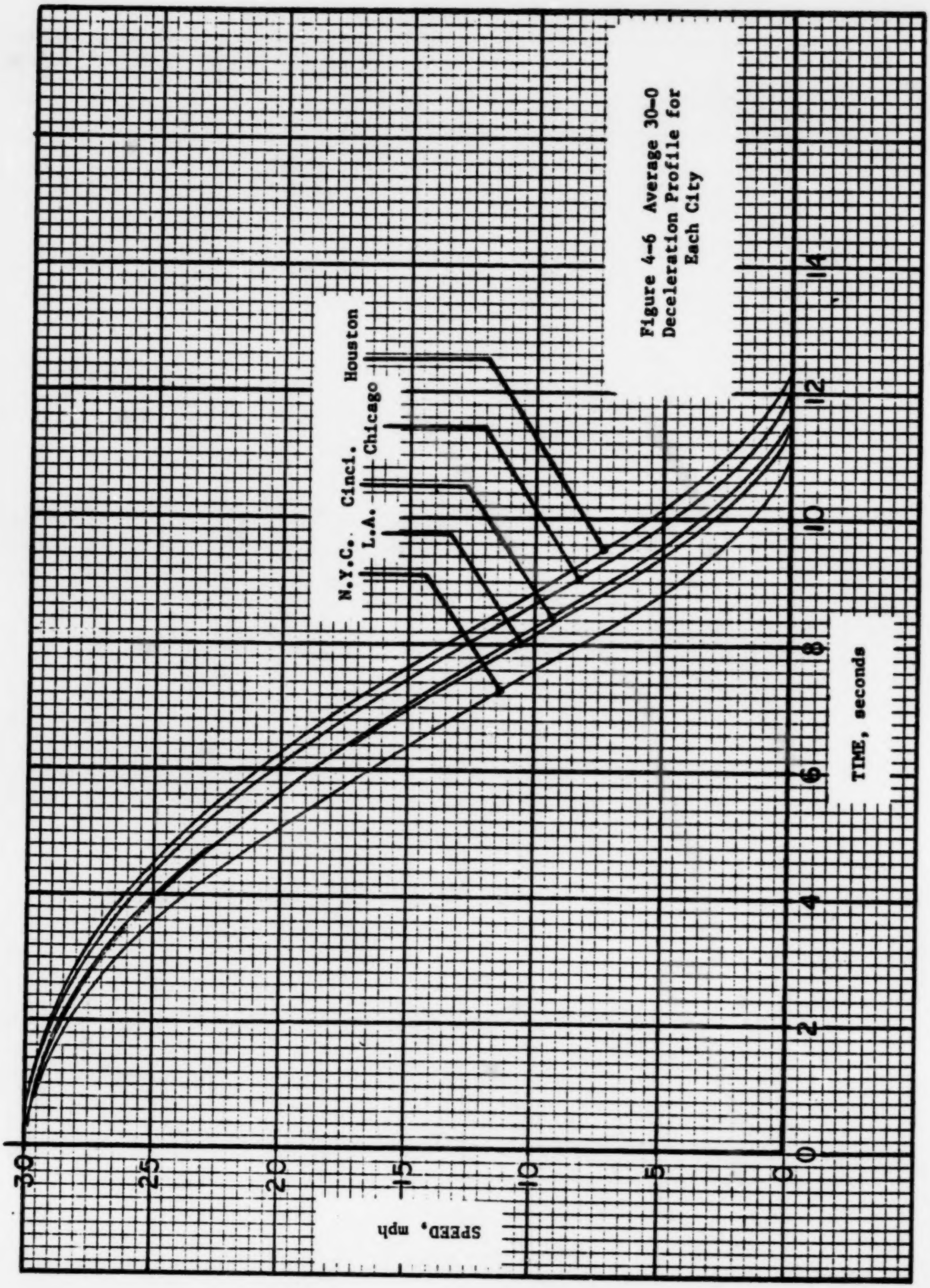


Figure 4-6 Average 30-0 Deceleration Profile for Each City

4.1.5.2 Intake Manifold Vacuum

The chase vehicles were equipped with pressure transducers for determining the intake manifold vacuum during survey operations. Although it is recognized that intake manifold vacuum conditions for the chase vehicle do not properly reflect the manifold vacuum characteristics of the vehicles being chased, due to major differences in engine size, vehicle weight, etc., the collected data do provide some useful information on vehicle operation. By determining the intake manifold vacuum levels at cruise conditions and comparing these data to road load manifold vacuum curves, it is possible to derive the approximate amount of time that the survey vehicle was operated at, or near, normal road load conditions.

Figure 4-7 presents the average of the manifold vacuum levels recorded at each cruise speed during the entire survey. Plots of manifold vacuum readings for several cruise speeds indicated the manifold vacuum data to be distributed approximately normally about the mean values. The two curves labeled A-2 and A-3 in Figure 4-7 represent ±2 standard deviations about the mean; it can therefore be expected that approximately 95% of the manifold vacuums at cruise fall between these upper and lower curves.

One of the chase vehicles was operated at various cruise speeds on a level road and at three different road grades to establish plots of cruise manifold vacuum versus percent road grade. The road load manifold vacuum curves for the vehicle operation on a level grade and on a 4.00% uphill and downhill grade are shown by the dashed lines in Figure 4-7. The proximity of the curves in this figure indicate that it would be reasonable

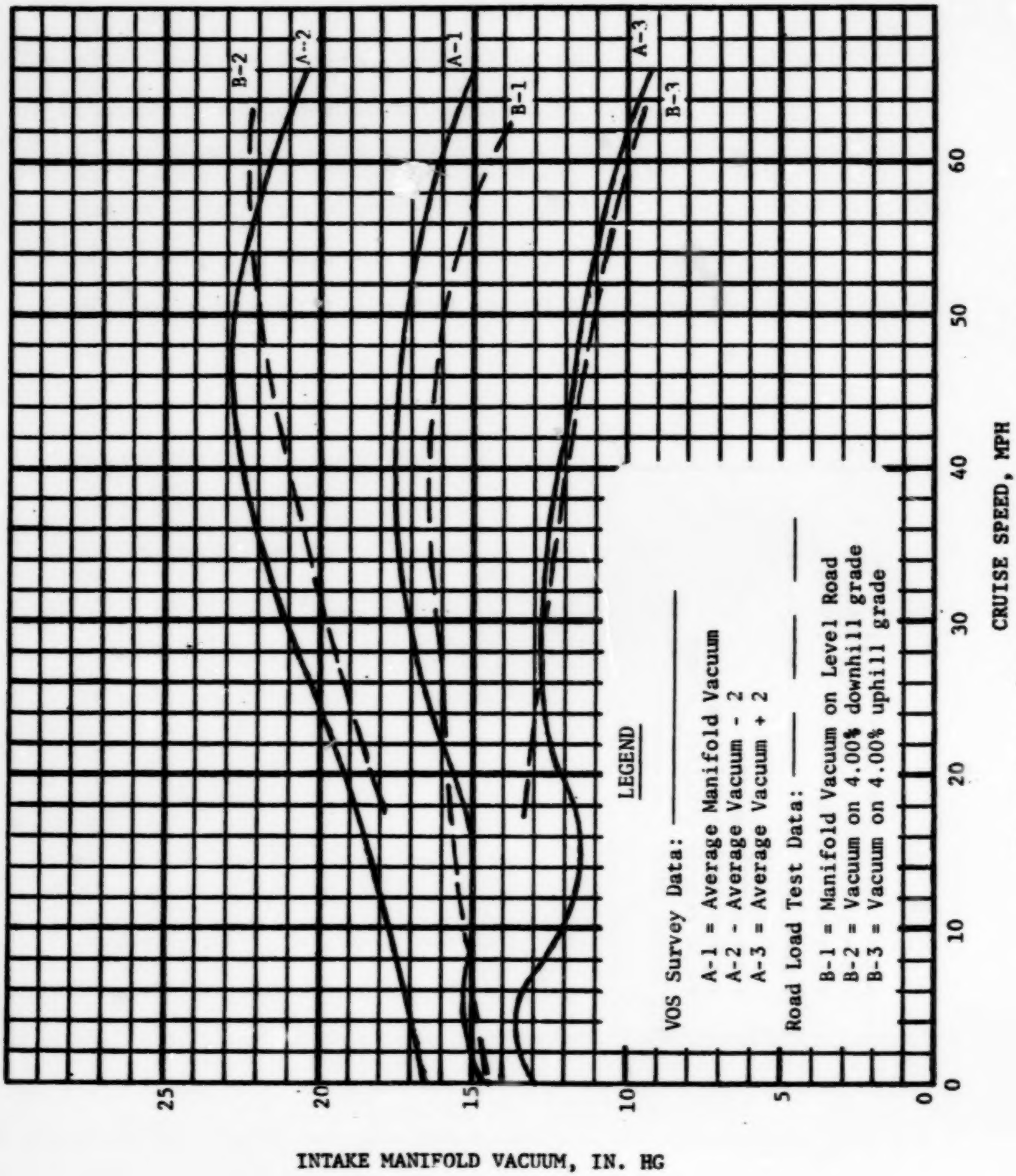


Figure 4-7 Intake Manifold Vacuum Versus Cruise Speed

to estimate that approximately 85-90% of the time the vehicles cruised on road surfaces which are within ±4.00% of level.

The data describing the manifold vacuum versus road grade data were collected in the San Bernardino, California area. All measurements were made with the vehicle air conditioning system operating. Field survey data were collected in the five cities with the air conditioning both operative and inoperative. This factor probably accounts for the small vertical displacement of the field survey data above the road test readings.

4.2 LOS ANGELES ROUTE REPLICATE EVALUATION

As discussed above, remarkably high matrix correlations between cities and for each city versus the composite were obtained. It was decided to investigate further the driving pattern variability within a city to permit further assessment of the delta-square and correlation values. The first city visited, Los Angeles, was surveyed for a longer time period than any of the other four cities. During a two-week time period, four separate weekday routes and four corresponding weekend routes were driven. Since each of four routes was driven twice daily for seven full days, a total of 56 route replicates was obtained. Each route replicate was compared with the Los Angeles composite to determine the variability of the data within Los Angeles.

4.2.1 Normalized Time in Mode Variability

Mode composition statistics for the route replicate time-in-mode matrices are given in Table 4-8. Each weekday route (Routes 1-4) was replicated 10 times and each weekend route (Routes 5-8) was replicated four times.

Table 4-8

Mode Composition For Route Replicates In Los Angeles - Percent Of Time In Mode

	Percent Time @ Idle		Percent Time @ Cruise		Percent Time @ Acceleration		Percent Time @ Deceleration	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Route No. 1	8.83	1.20	35.82	1.82	29.49	1.66	25.86	0.97
Route No. 2	9.41	1.55	33.46	1.95	30.92	1.09	26.20	0.56
Route No. 3	11.58	2.60	33.55	1.49	29.84	1.81	25.03	0.84
Route No. 4	10.51	2.42	34.22	1.79	28.84	0.48	26.44	1.14
Weekday Average	10.08	1.94	34.26	1.76	29.77	1.26	25.88	0.88
Route No. 5	8.61	1.67	35.06	3.19	30.19	1.96	26.14	0.79
Route No. 6	9.32	1.43	33.76	1.86	31.02	0.32	25.90	0.77
Route No. 7	11.12	1.82	34.69	0.98	29.42	1.89	24.78	0.79
Route No. 8	7.88	1.24	37.49	4.10	28.74	1.94	25.90	1.03
Weekend Average	9.23	1.54	35.25	2.53	29.84	1.28	25.68	0.84
Grand Average	9.84	1.83	34.54	1.98	29.79	1.26	25.82	0.87

4.2.2 Normalized Mode Frequency Variability

Table 4-9 presents the mode-composition statistics for the frequency matrices for the route replicates. The variability in the mode-frequency statistics is consistently less than the variability in percent-of-time statistics; i.e., mode frequencies are stable from one route to another, as well as from one city to another, as previously indicated.

4.2.3 Delta-Square Comparison of Route Replicates

The delta-square technique described in Section 3.5 was used to compare the matrix information generated for each route replicate with the corresponding Los Angeles composite matrices. Normalized time-in-mode matrix data and normalized mode-frequency matrix data were evaluated in this manner. A statistical summary of the results is given in Table 4-10.

4.2.4 Average Speed Variability

Table 4-10 also contains a speed summary showing the variability in average speeds for the route replicates. Average speeds for weekends indicated approximately the same degree of variability as average speeds for weekday route replicates.

4.2.5 Correlation Between Route Replicate Matrices and the Los Angeles Composite For Normalized Time in Mode Data

Table 4-11 presents the results of correlating each normalized time-in-mode matrix for a route replicate with the Los Angeles composite normalized time-in-mode matrix. The correlations computed for all replicates over the total matrix have an average value of 0.953.

4.2.6 Correlation Between Route Replicate Matrices and the Los Angeles Composite Matrix for Normalized Mode Frequency

Table 4-12 presents the results of correlating each normalized mode-frequency matrix for a route replicate with the corresponding Los Angeles

Table 4-9

Mode Composition For Route Replicates In Los Angeles - Percent Of Mode Frequency

	Percent Mode Frequency @ Idle		Percent Mode Frequency @ Cruise		Percent Mode Frequency @ Acceleration		Percent Mode Frequency @ Deceleration	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Route No. 1	7.36	0.73	42.64	0.73	25.01	0.40	24.99	0.40
Route No. 2	7.47	0.56	42.53	0.56	25.32	0.54	24.68	0.54
Route No. 3	7.54	0.71	42.46	0.71	25.24	0.40	24.76	0.40
Route No. 4	7.70	1.09	42.30	1.09	24.95	0.46	25.05	0.46
Weekday Average	7.52	0.77	42.48	0.77	25.13	0.45	24.87	0.45
Route No. 5	8.58	2.01	41.42	2.01	24.76	0.23	25.24	0.23
Route No. 6	8.28	0.30	41.72	0.30	24.80	0.17	25.20	0.17
Route No. 7	8.12	0.65	41.88	0.65	24.52	0.69	25.48	0.69
Route No. 8	6.69	1.32	43.31	1.32	24.42	0.28	25.58	0.28
Weekend Average	7.92	1.07	42.08	1.07	24.62	0.34	25.38	0.34
Grand Average	7.63	0.86	42.37	0.86	24.99	0.42	25.01	0.42

Table 4-10

Delta-Square Values and Average Speeds for Route Replicates in Los Angeles

	Delta-Square Normalized Time in Mode		Delta-Square Normalized Mode Frequency		Average Speed, mph	
	Mean	Range	Mean	Range	Mean	Std. Dev.
Route No. 1	5.03	1.66-8.76	2.89	0.91-5.58	29.50	1.63
Route No. 2	6.26	1.15-18.07	3.19	0.22-9.59	27.88	1.63
Route No. 3	3.60	1.05-12.37	2.23	0.51-7.60	28.36	1.22
Route No. 4	4.87	1.28-14.17	3.44	0.42-14.30	29.46	1.20
Weekday Ave.	4.94	1.05-18.07	2.94	0.22-14.30	28.80	1.42
Route No. 5	4.35	2.37-7.85	2.56	0.57-4.30	31.08	0.53
Route No. 6	2.91	2.03-3.76	1.82	1.45-2.28	30.42	1.00
Route No. 7	6.70	2.28-11.62	3.59	0.56-7.27	30.33	2.15
Route No. 8	9.48	5.01-18.64	9.22	6.74-12.38	32.61	1.86
Weekend Ave.	5.86	2.03-18.64	4.30	0.56-12.38	31.11	1.38
Grand Average	5.20	1.05-18.64	3.32	0.22-14.30	29.46	1.41

Table 4-11

Correlation of Route Replicates with LA Composite Matrix; Normalized Time-in-Mode

	Cruise Modes		Acceleration Modes		Deceleration Modes		Total Matrix	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Route No. 1	0.932	0.889-0.974	0.917	0.864-0.947	0.922	0.882-0.951	0.955	0.935-0.977
Route No. 2	0.909	0.754-0.970	0.919	0.876-0.955	0.924	0.874-0.971	0.946	0.892-0.976
Route No. 3	0.959	0.922-0.988	0.931	0.872-0.970	0.925	0.831-0.967	0.964	0.925-0.986
Route No. 4	0.933	0.787-0.982	0.915	0.814-0.942	0.901	0.778-0.957	0.954	0.904-0.977
Weekday Ave.	0.936	0.754-0.988	0.921	0.814-0.970	0.919	0.778-0.971	0.955	0.892-0.986
Route No. 5	0.918	0.837-0.951	0.938	0.916-0.949	0.939	0.922-0.961	0.950	0.928-0.962
Route No. 6	0.940	0.921-0.960	0.944	0.905-0.965	0.940	0.904-0.966	0.960	0.949-0.970
Route No. 7	0.932	0.886-0.948	0.936	0.881-0.959	0.924	0.854-0.964	0.952	0.911-0.962
Route No. 8	0.849	0.629-0.931	0.893	0.835-0.918	0.898	0.866-0.937	0.923	0.816-0.962
Weekend Ave.	0.916	0.629-0.960	0.930	0.835-0.970	0.927	0.854-0.966	0.948	0.816-0.970
Grand Average	0.931	0.629-0.988	0.924	0.814-0.970	0.921	0.778-0.971	0.953	0.816-0.986

Table 4-12

Correlation of Route Replicates with LA Composite: Normalized Mode Frequency

	Cruise Modes		Acceleration Modes		Deceleration Modes		Total Matrix	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Route No. 1	0.948	0.850-0.990	0.898	0.856-0.939	0.900	0.834-0.935	0.972	0.943-0.989
Route No. 2	0.956	0.872-0.990	0.921	0.859-0.961	0.926	0.864-0.964	0.976	0.947-0.993
Route No. 3	0.967	0.915-0.984	0.935	0.877-0.969	0.932	0.887-0.962	0.980	0.956-0.988
Route No. 4	0.943	0.764-0.985	0.903	0.728-0.938	0.902	0.804-0.950	0.970	0.907-0.987
Weekday Ave.	0.955	0.764-0.990	0.915	0.728-0.969	0.916	0.804-0.964	0.975	0.907-0.993
Route No. 5	0.963	0.941-0.977	0.910	0.868-0.945	0.904	0.831-0.941	0.975	0.962-0.987
Route No. 6	0.976	0.947-0.991	0.933	0.908-0.947	0.927	0.909-0.942	0.982	0.973-0.988
Route No. 7	0.948	0.930-0.963	0.918	0.871-0.942	0.915	0.827-0.940	0.969	0.953-0.978
Route No. 8	0.868	0.748-0.904	0.854	0.768-0.890	0.868	0.804-0.908	0.945	0.895-0.957
Weekend Ave.	0.950	0.748-0.991	0.907	0.768-0.947	0.906	0.804-0.942	0.970	0.895-0.988
Grand Average	0.953	0.748-0.991	0.913	0.728-0.969	0.913	0.804-0.964	0.974	0.895-0.993

composite matrix. The average value of r resulting from this comparison was 0.974 (total matrix correlation).

4.2.7 Summary of Route Replicate Evaluation

The evaluation of driving patterns for each replicate was performed on the Los Angeles survey data; however, a preliminary look at replicate data for the other cities makes reasonable the assumption that variability within those other cities is of the same order as that for Los Angeles. Table 4-13 presents a summary of data obtained from the distribution functions of the evaluation measures for the route replicates.

4.3 DETROIT ROAD ROUTE

The primary objective of the CRC Project No. CAPE-10-68 was to collect and evaluate information on urban traffic patterns and detailed vehicle modal operating characteristics. Another objective was to design and evaluate a road route on the metropolitan Detroit area which would produce vehicle operating data typical of the national average patterns. Therefore, a basic road route was layed out in the greater Detroit metropolitan area. The route was designed to yield vehicle operating patterns representative of the five-city composite pattern.

4.3.1 Design of the Detroit Metropolitan Road Route

The road route was actually located in the city of Ann Arbor, Michigan at a distance of approximately 35 miles from downtown Detroit. This site was selected as being easily accessible to the EPA vehicle emission test group which was recently relocated in Ann Arbor near the University of Michigan Campus.

Table 4-13

Summary of Route Replicate Evaluation

Comparison With L.A. Composite	Remarks
1. Correlation of Normalized Time in Mode Data	90% of all replicates resulted in r values greater than 0.910
2. Correlation of Normalized Mode Frequency Data	90% of all replicates resulted in r values greater than 0.951
3. Delta-Square for Normalized Time-in-Mode Data	90% of all replicates resulted in Δ-squares of less than 11.62
4. Delta-Square for Normalized Mode Frequency Data	90% of all replicates resulted in Δ-squares of less than 7.60
5. Average Speed - Weekdays	90% of all replicates were within ± 2.77 mph from the mean value
6. Average Speed - Weekends	90% of all replicates were within ± 3.18 mph from the mean value

4.3.1.1 Route Design Criteria

The construction of the Detroit road route was guided by the following basic design objectives:

1. Vehicle operating patterns on the route should be representative of the five-city composite patterns
2. Repeated operation on the route should produce minimum variability in vehicle operating patterns
3. The route should require approximately 20-30 minutes for one lap.

To be representative of the five-city composite driving patterns, operation on the Detroit road route should result in the following characteristics:

5-City Composite Results

Average Speed, mph	26.0
Time @ Idle, %	13.06
Time @ Cruise, %	31.50
Time Accelerating,%	29.16
Time Deceleration,%	26.30
Idle Frequency, %	7.59
Cruise Frequency, %	42.41
Acceleration Frequency, %	25.26
Deceleration Frequency, %	24.74

In addition to satisfying the above criteria, it was necessary to specify an appropriate variety of operating modes so that delta-square comparisons would yield minimum values and correlation coefficients would be as high as possible.

The route was designed for operation between the hours of 9:00 a.m. and 4:00 p.m. to minimize the variability associated with peak morning and afternoon traffic congestion. Additionally, the route was located so as to avoid the central city and the main campus areas, since they were judged to be sources of both day-to-day and seasonal variability.

4.3.1.2 Route Construction

Three road routes, designated Route 30, Route 40, and Route 50, were mapped out for collection of data. The three routes varied only slightly, the freeway segments of each being identical. Table 4-14 presents information on the construction of the three routes. The routes were located on the eastern side of Ann Arbor. Route directories and maps describing all three routes are included in Appendix B.

4.3.2 Operating procedures

Vehicle operating procedures specified for this task were basically the same as those used for the collection of data in the 5 cities. The procedures which were unique to this effort were:

- Collection of data was restricted to the time period 9:00 a.m. to 4:00 p.m.
- Deletion of the chase car technique during data collection.

The schedule for collecting data on the routes is shown in Figure 4-8. As indicated, each route was driven three times daily over 6 days for a total of 18 replicates per route.

The data were processed using the same computer programs used previously to allow comparisons with the composite driving pattern descriptors and also comparisons between routes.

4.3.3 Results

Analysis of the data collected on the three routes indicated that this task was accomplished successfully, although the driving patterns attributed to these routes differed from the five-city composite

Table 4-14

Construction Characteristics of Detroit (Ann Arbor) Road Routes

	Route 30	Route 40	Route 50
Total Length, Miles	9.35	11.16	13.01
Non-Freeway Miles	7.00	8.81	10.66
Freeway Miles	2.35	2.35	2.35
Freeway Mileage, %	25.2	21.0	18.1
Traffic Lights	4	4	7
Stop Signs	9	12	10

July 13	July 14	July 15	July 16	July 17	July 18	July 19
Vehicle Preparation and Practice Driving on All Routes	Route 30*	Route 40	Route 50	Route 30	Route 40	Route 50
	Route 40*	Route 50	Route 30	Route 40	Route 50	Route 30
	Route 50*	Route 30	Route 40	Route 50	Route 30	Route 40

* Each route driven three times per day

Figure 4-8 Data Collection Schedule For Detroit (Ann Arbor) Road Routes

patterns in some respect. Operating characteristics for the three routes are summarized in Table 4-15.

The average speed on each route compares favorably with the five-city composite. Statistics depicting the percent of time spent in the four general mode categories were much lower than desired for percent idle time and higher than desired for percent cruise time. Percent of time accelerating was only slightly higher than the composite value and percent of time decelerating was nearly identical to the desired value. For these reasons, matrix comparison by correlation techniques yielded low values of r, and the delta-square values were inordinately high.

The route statistics describing the percent mode frequency of occurrence for the same four categories indicated the stability already noted. Vehicle operation on all three routes yielded values of percent mode frequency which were comparable to the five-city composite values for all four mode categories. Route 40 had the least favorable statistics for mode-frequency data.

In general, the descriptive statistics for the three routes indicated less similarity to the five-city composite than did those for any other comparison of a city versus the composite or those for comparisons between any two cities. This was to be expected because of the short lengths of the Detroit (Ann Arbor) routes and the fact that the area being surveyed presented a non-typical survey environment. The factors believed to be responsible for these results are:

Table 4-15

Comparison of Vehicle Operating Patterns on Detroit Road Routes with the Five-City Composite Results

	Route 30	Route 40	Route 50	5-City Comp.
Average Speed, mph	27.2	26.0	26.5	26.0
Time @ Idle, %	3.8	3.2	5.1	13.1
Time @ Cruise, %	36.6	39.0	39.6	31.5
Time Accelerating, %	32.8	32.0	29.4	29.2
Time Decelerating, %	26.8	25.8	25.9	26.3
Time: Correlation	0.61	0.47	0.61	1.00
Time: Delta-Square	24.2	60.7	29.3	0.0
Idle Frequency, %	7.9	5.2	5.7	7.6
Cruise Frequency, %	42.1	44.8	44.3	42.4
Acceleration Frequency, %	25.4	25.5	24.8	25.3
Deceleration Frequency, %	24.6	24.5	25.2	24.7
Frequency: Correlation	0.87	0.62	0.87	1.00
Frequency: Delta Square	8.8	24.3	7.3	0.0
Length, miles	9.35	11.16	13.01	---
Average time, hrs.	0.343	0.429	0.490	---

- Short length
- Lack of traffic congestion
- Few traffic lights
- Lack of variety of available road types (Ann Arbor's population is only 98,414 and the area involved is only 15 square miles).

The first two items, although they contribute to the differences, are necessary for the development of a repeatable road route.

Analysis of the data representing the three routes indicates that minor changes would be adequate to improve the statistics for the driving patterns. While actual changes in the physical structure or location of certain portions of the routes would also improve the statistics, additional data collection time would be required to verify this approach. Instead of changing the composition of the routes, restrictions in driving behavior can be applied.

To illustrate this approach, two examples are offered. Since the descriptor of vehicle operating patterns which deviates the greatest from the five-city composite data is the percent of time at idle, this value can be altered to approximate the desired value. This can be achieved by specifying a lengthy initial idle mode (typical of cold start operation) and by increasing the idle time at other selected places throughout the routes.

To illustrate how this approach affects the descriptive statistics, Route 30 and Route 50 were artifically altered by adding 92 and 97 seconds of idle time, respectively. Table 4-16 presents the new route statistics as determined by this one change. The quality of these results indicates that both Route 30 and Route 50 now provide relatively good representation of the average driving patterns. It appears highly

Table 4-16

Improvement of Detroit Road Route Characteristics by Adding Idle Time

	Route 30	Synthe-sized Route 35*	Route 50	Synthe-sized Route 55**	5-City Composite
Average Speed, mph	27.2	25.4	26.5	25.2	26.0
Time @ Idle, %	3.8	10.5	5.1	10.0	13.1
Time @ Cruise, %	36.6	34.1	39.6	37.6	31.5
Time: Accelerating, %	32.8	30.5	29.4	27.9	29.2
Time: Decelerating	26.8	24.9	25.9	24.5	26.3
Time: Correlation	0.61	0.79	0.61	0.73	1.0
Time: Delta Square	24.2	15.4	29.3	24.1	0.0

* Created by adding 92 seconds of idle time to Route 30

** Created by adding 97 seconds of idle time to Route 55 probable that additional restrictions on driver behavior, combined with minor changes in the physical design, would result in road routes which are representative of average driving patterns.

4.4 SUMMARY OF RESULTS

The successful completion of the Vehicle Operation Survey has provided a data bank on typical driving patterns encompassing five major urban areas. The Digital Data Acquisition Systems, route design techniques, data collection procedures, and data processing routines all proved to be highly appropriate for this effort as well as adaptable to other studies of a similar nature.

More specifically, VOS program experience permits the following summary:

1. The Digital Data Acquisition Systems described herein provide an adequate method of obtaining data on vehicle operating characteristics.
2. The chase-car concept used in this program was an accurate method for emulating driving habits of the traffic population.
3. Data collection routes of approximately 150 miles in length adequately represent vehicle usage patterns.
4. Vehicle modal operating patterns are conveniently characterized with the use of matrices of events based on initial speed versus final speed.

The data collected in the 5 cities were combined (weighted) in proportion to the number of vehicles registered in the respective areas. Composite driving patterns obtained in this manner may be summarized as follows:

1. 13.06% of the time that vehicles are in operation on the road is spent at idle.

2. The time spent at cruise conditions is 31.50% of the total time. The most frequent cruise speeds are between 27.5 mph and 37.5 mph. Vehicle cruising above 45 mph is most likely to occur in the range of 65-70 mph.

3. Total time spent accelerating is slightly higher (29.16%) than time spent decelerating (26.30%). In nearly every mode involving a speed change the decelerations occur at slightly higher rates than corresponding accelerations for the same speed difference.

4. The overall average speed was 25.97 mph. Average speed on freeway type roads (limited access) was 46.49 mph and vehicle speeds on non-freeway roads equalled 21.33 mph.

Analysis of the data for the individual cities indicates the following general trends:

1. Los Angeles exhibited the fastest overall average speed of 29.34 mph and New York City had the slowest average speed, 21.64 mph.

2. Los Angeles drivers spent the least amount of time at idle, 10.13%; New York City had the highest value, 17.45%.

3. Based on the most frequent acceleration and deceleration modes, 0-30 mph and 30-0 mph respectively, the typical acceleration and deceleration speed-time profiles are essentially the same for the five cities.

4. Analysis of the 56 route replicates in Los Angeles indicate less variability than initially expected.

5. Vehicle operating patterns on the LA-4 Route, which typifies driving characteristics during peak hours in central Los Angeles, are notably different from the patterns for the entire metropolitan area, as expected.

Analysis of the data collected over the routes constructed in Ann Arbor indicates the following:

1. Preliminary efforts to construct a road route which represents the average driving patterns were partially successful.
2. Further modifications to the structure of the Detroit (Ann Arbor) road routes will result in a repeatable and representative road route.

REFERENCES

1. "A Survey of Average Driving Patterns in the Los Angeles Urban Area;" System Development Corporation, TM(L)4119/000/00, February 28, 1969.

2. "A Survey of Average Driving Patterns in the Houston Urban Area;" System Development Corporation, TM(L)4119/001/00, August 28, 1969

3. "A Survey of Average Driving Patterns in the Cincinnati Urban Area;" System Development Corporation, TM(L)4119/002/00, September 30, 1969.

4. "A Survey of Average Driving Patterns in the Chicago Urban Area;" System Development Corporation, TM(L)4119/003/00, November 26, 1969.

5. "A Survey of Average Driving Patterns in the Minneapolis - St. Paul Urban Area;" System Development Corporation, TM(L)4119/004/00, February 13, 1970.

6. "A Survey of Average Driving Patterns in the New York Urban Area;" System Development Corporation, TM(L)4119/006/00, August 15, 1970.

7. "A Survey of Average Driving Patterns in Six Urban Areas of the United States: Summary Report'" System Development Corporation, TM(L)4119/007/00, January 29, 1971.

8. "A Study of Los Angeles Driving As It Relates to Peak Photochemical Smog Formation;" J. N. Pattison and M. P. Sweeney, Air Pollution Control Association Presentation, June 1966.

9. "Laboratory Simulation of Driving Conditions in the Los Angeles Area;" G. C. Hass and J. N. Pattison, SAE Paper 660546, August 1966.

10. "Vehicle Operations Survey: Interim Report, LA-4 Road Route Study;" M. Smith and M. Manos, Scott Research Laboratories, Inc.; SRL 2922-09-1071, October 29, 1971.